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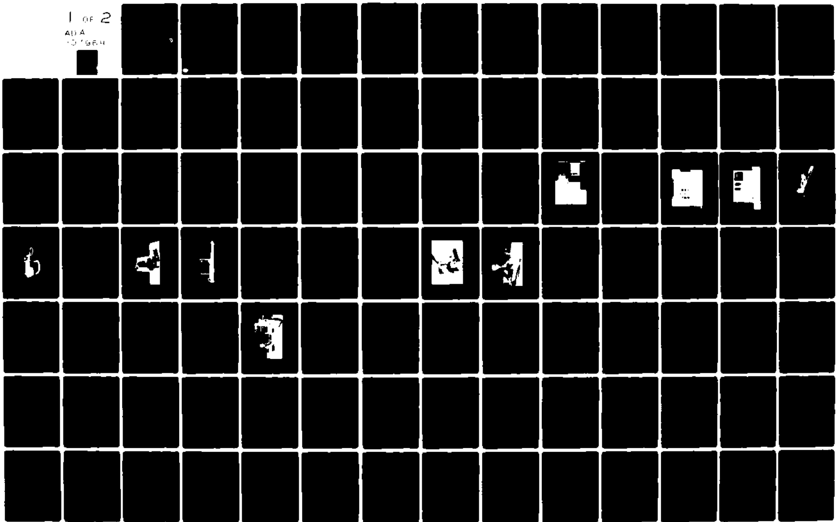

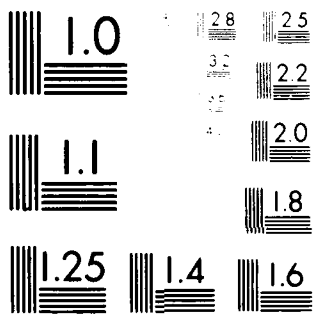


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CHANGES IN SYSTOLIC BLOOD PRESSURE DURING ISOMETRIC CONTRACTIONS OF DIFFERENT SIZE MUSCLE GROUPS

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# CHANGES IN SYSTOLIC BLOOD PRESSURE DURING ISOMETRIC CONTRACTIONS OF DIFFERENT SIZE MUSCLE GROUPS

by

Joe A. Buck

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Arts in Physical Therapy
in the Graduate College of
The University of Iowa

May, 1979

Thesis supervisor: Assistant Professor Louis R. Amundsen

Graduate College
The University of Iowa
Iowa City, Iowa

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MASTER'S THESIS

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This is to certify that the Master's thesis of

Joe A. Buck

has been approved by the Examining Committee for the thesis requirement for the Master of Arts degree in Physical Therapy at the May, 1979 graduation

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I thank God for providing me with the opportunity, help, and strength to complete this study.

This thesis is dedicated to Kathy, Clint, and Jason.

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# CHAPTER I

# INTRODUCTION

## Background of the Study

Since many of our daily activities contain elements of an isometric nature, for example, holding a box while lifting it, brushing our teeth, combing our hair; our cardiovascular system must routinely adapt and function during these stresses. DeVries(4) and Lind (8,9,11) have demonstrated that the pressor response during activities containing both rhythmic and static components is primarily governed by the isometric component. Characteristic cardiovascular responses to static contractions are (1) substantial rises in both systolic and diastolic blood pressures, (2) small changes in heart rate, and (3) minimal, if any, changes in the peripheral vascular resistance(3). The monitoring of the heart rate is not the most adequate means of assessing the cardiac stress of an exercise containing an isometric component since the pressure load imposed on the heart, demonstrated by changes in the systolic and diastolic blood pressures, is more significant than the exercise tachycardia.

Cardiac effort or myocardial oxygen cost during exercise ($M\dot{V}O_2$) can be most accurately predicted using the pressure-rate product (heart rate times systolic blood pressure)(2,9,13). Having an accurate assessment of the pressure load, as indicated by the systolic blood pressure, imposed upon the myocardium by the isometric components of an exercise program would be valuable for exercise prescription and activities of daily living (ADL) counseling following myocardial infarction.

Investigations conducted by Donald(1), Lind(2), and a review of literature by Nutter(3) state that the blood pressure response to an isometric contraction is governed by two factors: (1) the intensity of the isometric contraction, and (2) the duration of the contraction. Studies by Donald(1), Lind(2), DeVries(4), Fisher(5), and Humphreys(6), have shown a positive relationship between the percent of the maximal voluntary contraction (MVC) and the magnitude of the systolic blood pressure observed during the contraction. Astrand(7), Lind(2,8,9), and DeVries(4) conclude from their studies that the systolic blood pressure response during an isometric contraction is determined not by the size of the contracting muscle mass, but by its relative proportion of MVC. This assumption is plausible considering their data; however, McCloskey(10),

using electrical stimulation, demonstrated on anesthetized dogs and cats that the size of the contracting muscle did influence the magnitude of the pressor response.

Although Lind(8,9), Humphreys(6), and McCloskey(10) all state that the change in systolic blood pressure is proportional to the percentage MVC of the isometric contraction, there is no agreement among them as to how much change will occur at a given percent MVC. All three of these investigators studied a relatively small number of subjects: Lind, ten subjects in one study(8), four in the other(9); Humphreys, four subjects(6); McCloskey, ten subjects(10). None of the investigators attempted to control nor did they mention how they compensated for the contribution of the accessory muscle activity to the blood pressure response observed in the individual studies. With the exception of McCloskey(10) who used arterial catheterization, blood pressure was measured by auscultation, using a pressure cuff and stethescope. Due to the psychological and physiological changes that cause fatigue, it is difficult to study absolute systolic blood pressure values measured indirectly at isometric tensions greater than 50% MVC due to the relatively short duration of the contraction. Although these studies and others(2,11,12,34) have described pressor responses of

different muscle groups at various percentages of MVC, no literature is available which tested the statistical significance of differences between the characterized responses of large and small muscles. Previous studies have not utilized sufficiently large numbers of subjects or valid techniques of measuring blood pressure. Nor have previous studies eliminated or accounted for accessory muscle activity which could have contributed to the observed blood pressure responses. Thus, an objective investigation of the systolic blood pressure response to isometric contractions of different size muscle groups, which would minimize the criticisms of the above mentioned studies, is needed.

Purpose of the Study

The purpose of this study was to investigate the difference between the systolic blood pressure responses to two different size muscle masses contracting at a known percentage of maximum voluntary strength. Specifically, this study compared slopes and intercepts of the regression lines derived from systolic blood pressure responses during sustained contractions of two different size muscle groups contracting at 40% MVC.

## Limitations of the Study

Certain factors which can be considered as limitations to this study include:

1) The inability to measure precisely the size of the contracting muscle mass.
2) Inability to completely assess or eliminate synergistic and/or co-contracting muscle activity.
3) Validity of maximum tension measured as actually being the maximum tension possible for the individual subjects.
4) The psychological and physiological fatigue factors influencing the duration of the isometric contractions.
5) A population limited to normal males between the ages of 20 and 33 years.
6) The use of an intermittent noninvasive rather than a continuous invasive technique for measuring blood pressure.

Definition of Terms

Muscle Mass. The amount of muscle tissue in the muscle or muscle group producing the specific isometric contraction.

Fatigue Contraction. The sustained contractions of the two different size muscle groups performed until a cut-off critereon is observed.

Maximal Isometric Tension. Mean value of three brief maximal isometric contractions each of 3 seconds duration and with 1 minute rest between contractions.

Cut-off Criterion for Muscle Tension. Isometric muscle tension during a sustained contraction which was 10% less than the designated 40% tension.

Maximal Accessory Muscle Activity. Level of integrated EMG activity recorded from surface electrodes over the most likely synergistic and/or co-contracting muscles during a 100% MVC of the specific accessory muscles.

Cut-off Criterion for Accessory Muscle Activity. Integrated EMG activity recorded from surface electrodes over the most likely synergistic and/or co-contracting muscle, which does not exceed 10% of the maximal accessory activity.

# CHAPTER II

## REVIEW OF LITERATURE

This chapter presents a review of literature pertinent to the measurement of isometric strength and endurance and a thorough review of literature relevant to the blood pressure response to isometric exercises.

### Strength and Isometric Endurance Measurements

In his book on work and fatigue(15), Simonson identifies some of the physiological and psychological factors to consider when measuring maximal isometric muscle strength and submaximal isometric endurance contractions. Investigators studying the relationship between isometric strength and isometric endurance have calculated test-retest correlation coefficients (r) as an indication of the reliability of their measurements. Carlson(16,17) obtained r values, indicative of his between day reproducibility, of .95 and .60 to .68 for maximal isometric strength and submaximal isometric endurance, respectively, in a study using handgrip as the isometric contraction and between day r values of .94 and

.48 to .73 for strength and endurance, respectively, in a study utilizing the elbow flexors. Heyward(18) studied handgrip strength and endurance and obtained between day test-retest r values of .92 to .98 for 100% MVC strength and .65 to .88 for endurance. While testing the validity of a dynometer to measure isometric strength of the intrinsic muscles of the hand, Less(19) obtained a test-retest r value of .89 to .94 for adduction of the index finger.

## Blood Pressure Response to Isometric Exercise

Although Gaskell(20), as early as 1877, and Grant(21), Clark, et al.(22), and Tuttle and Horvath(23) in later years had described some of the physiological changes that occur in the cardiovascular system during exercise, it was not until the mid-1960's that studies were conducted that specifically evaluated the cardiovascular changes as they relate to sustained isometric contraction. In contrast to dynamic exercise which characteristically manifests itself with a marked increase in both heart rate and cardiac output, and a decrease in total vascular resistance, sustained isometric exercise is manifested by rapid increases in systolic and, to a lesser degree, diastolic arterial blood pressure,

less dramatic increases in heart rate and cardiac output, and little, if any, increase in total systemic vascular resistance(3).

In 1963 Humphreys and Lind(6) published the results of the first investigation which studied the relationship between intramuscular pressure and perfusion pressure of the blood at different percentages of maximal voluntary contraction (MVC). Blood flow to the active muscles in the forearm was measured during repeated 30, 40, 50, 60, and 70% MVC handgrip contractions of four healthy middle aged male subjects. The contractions were maintained until fatigue. Fatigue was defined as the instant at which the specified tension could no longer be maintained, and measured to the nearest second. Forearm blood flow measurements were taken prior, during, and post exercise. Because of possibly inaccurate measurements at 70% MVC, only the data collected at the lower tensions were presented for discussion. Using bipolar needles to determine the "...functional anatomy of the forearm muscles during the contractions...", the prime movers were defined as the extensor carpi radialis, flexor digitorum sublimis, and the flexor digitorum profundus. There was no electromyographic evidence of activity from the flexor carpi radialis or the flexor carpi ulnaris. Blood pressure

was measured by auscultation on the opposite arm prior, during, and post contraction.

At all tensions, there was a 10-20 mmHg rise in systolic blood pressure during the first 10-15 seconds of the isometric contraction and the observed systolic blood pressure at fatigue in all cases ranged from 170-190 mmHg. Since blood flow, and not blood pressure, was the major investigative factor, there was a relative paucity of data and discussion related to the blood pressure changes. Humphreys and Lind concluded that the blood flow directed toward the active muscles was increased at all relative submaximal tensions investigated, but there was a gradual increase of the intramuscular pressure of the contracting muscles as the percent of MVC increased from 30-70% such that at 70% MVC the intramuscular pressure exceeded the perfusion pressure of the blood and the flow to the active muscles was completely occluded. In light of this fact, it is reasonable to assume that the observed increase in systolic blood pressure was the body's attempt to maintain adequate blood flow to the active muscles in spite of the increasing intramuscular pressure.

In 1964, Lind, et al.(2), published the results of an investigation designed to look at the changes in aortic blood pressure, heart rate, cardiac output, and blood flow

during isometric handgrip contractions of varying relative intensities. Using four subjects, data was obtained from 10 and 20% MVC each held for 5 minutes and a 50% contraction held to fatigue (1 minute for two subjects, 2 minutes for the other two), being defined as the instant at which the subject could no longer maintain the contraction. During the 10% MVC there was an average mean aortic blood pressure (diastolic + 1/3 pulse pressure) increase of 10 mmHg and 7 beats/min in heart rate. The mean aortic pressure and heart rate of three of the four subjects remained in a steady state condition during the final 3 minutes of the contraction period. The mean aortic pressure and heart rate had returned to resting values within 30 seconds following release of the contraction. All four subjects showed a continuous increase in both mean aortic pressure and heart rate, 32 mmHg and 26 beats/min respectively, during the 20% MVC. These two parameters again returned to resting values within a short time, 1 minute, following release of the contraction. The average increases in mean aortic pressure and heart rate for all four subjects at 1 minute were 40 mmHg and 48 beats/min respectively during the 50% MVC. One minute was the fatigue point for two of the subjects, but the other two subjects maintained this

contraction for 2 minutes. The fatigue values for these two subjects were increases of 57 mmHg for mean aortic pressure and 57 beats/min. for heart rate. Whether held for 1 minute or 2 minutes, the mean aortic pressure and heart rate both returned to normal conditions within 1 minute following cessation of the contraction. These authors acknowledged the fact that extraneous muscle activity during the sustained contractions was possible, but failed to consider this in discussing the obtained data. They concluded that the pressor response to an isometric contraction was governed by the relative tension of the contracting muscle mass.

As a follow-up to some of his previous work(9), Lind, et al.(24) conducted two series of experiments designed to look at the responses to non-fatiguing, which he defined as being less than 15% MVC, and fatiguing, which he defined as being greater than 15% MVC, isometric contractions. The first series compared the cardiovascular responses during the sustained isometric contractions; the second series investigated the effects of arterial occlusion on the post-exercise hyperaemia. Using nine subjects, the investigators observed blood pressure, via auscultation every minute pre- and post-exercise and every 30 seconds during contraction using a

microphone stethoscope, and heart rate during four 3 minute contractions at 5, 10, 15, and 20% MVC each. Data was obtained from a 30% MVC separately to ensure that the cardiovascular changes observed were not influenced by the previous contractions.

In all instances, a steady state systolic blood pressure and heart rate was achieved early in the 5 and 10% MVC and maintained throughout the remainder of the 3 minute contraction. There was a continuous rise of both blood pressure and heart rate throughout the entire 3 minutes during all contractions greater than 15% MVC. The average increments of change for the four subjects for each 3 minute contraction were:

| Percent MVC | Blood Pressure (in mmHg) Systolic/Diastolic | Heart Rate (beats/min) |
|---|---|---|
| 5 | 10/8 | 4 |
| 10 | 13/12 | 6 |
| 15 | 14/13 | 8 |
| 20 | 18/16 | 11 |
| 30 | 27/23 | 26 |

The authors failed to discuss the rates of change observed in these parameters. Both blood pressure and heart rate always returned to normal values within 1 minute following release of the contraction. Based on the data from this investigation and previous studies, these investigators concluded that at tensions less than 15% MVC, the

cardiovascular system was able to maintain an adequate blood supply to the active muscles for an indefinite period of time, but at tensions greater than 15% MVC, fatigue was inevitable due to an insufficient blood supply. The blood flow to the active tissue, and therefore the duration of the contraction, was dependent on the relative tension of the contracting muscle mass.

Lind and McNicol(9) next set out to investigate the cardiovascular changes to isometric contractions performed in combination with other exercises, both dynamic and static. Using four subjects, 20% handgrip (5 minute duration), 30% (2.5 minutes), and 50% (about 1 minute: until fatigue) MVCs were each performed during treadmill walking at three different work rates (1.1, 1.7, and 2.8 l/min). Systolic blood pressure was measured at 30 second intervals via auscultation and heart rate was monitored via a continuous ECG. Both of these parameters showed a continuous rise during each isometric contraction period. Although absolute values differed, increments of change were similar (systolic blood pressure increased 30 mmHg, 40 mmHg, and 45 mmHg, at 20, 30, and 50% MVC respectively) for all workloads.

Again using the same four subjects, the cardiovascular changes were observed when there was an

isometric contraction of the right hand alone, right hip flexors alone, and the right hip flexors simultaneously at identical relative tensions during each set of contractions. Increments of change in both heart rate and systolic blood pressure were similar for all combinations of contractions at each of the intensities investigated (20, 30, 50% MVC). Similarly, using control handgrip contractions of 10 and 20% MVC, the preceding combination of contractions were simultaneously performed at 30 and 40% MVC respectively. Observed increments of change were similar to those observed during the previous sets of isometric contractions.

Based on these findings, the authors concluded that: (1) the increase in blood pressure resulting from an isometric contraction performed during a steady-state dynamic exercise will not be influenced by the dynamic component; the amount of change will be the same as if the isometric contractions were performed without the dynamic exercise, (2) the pressor response resulting from two or more simultaneous isometric contractions will be regulated by the contraction at the highest percent MVC, and (3) during an isometric contraction, the magnitude of change in blood pressure is dependent on the percent MVC of the contracting muscle regardless of the mass involved. They

do hypothesize, though, that "...there may be a lower limit of muscle mass which elicits the response...".

Lind and McNicol, conceding to the fact that although the cardiovascular responses observed in the previously described studies may have been correct, these changes had been produced under controlled, artificial environmental conditions and it was possible that identical changes would not occur in a situation which more closely simulated daily activities. This was the basis behind the design of their next study(8). While standing, ten right handed subjects held a 20 kg weight for 2.5 minutes in the right hand alone, in the left hand alone, and in each hand simultaneously. Blood pressure was measured at 30 second intervals via auscultation using a microphone stethoscope and heart rate was monitored continuously by ECG. All ten subjects showed identical patterns of response: continously increasing systolic and diastolic blood pressures and heart rate during the contractions, all three of which quickly returned to normal values following release of the contraction. The average mean blood pressure (diastolic + 1/3 pulse pressure) increase to holding the weight in the left hand alone or in each hand simultaneously was 48 mmHg, while the corresponding value for the right hand was only 35 mmHg. Heart rate increases

were 22 and 19 beats/min respectively. Each subject then lifted 40 kg in a specially designed shoulder harness. The heart rate and mean blood pressure showed initial increases of 6 beats/min and 23 mmHg, respectively, which were then maintained constant until the weight was released. Based on conclusions from previous investigations(5,9) this exercise was defined as a non-fatiguing contraction.

As demonstrated by holding different amounts of weight, when a non-fatiguing weight was held in either hand alone, in both hands simultaneously, or carried in the shoulder harness, both the mean blood pressure and heart rate plateaued and remained constant throughout the remainder of the exercise, whereas during an exercise involving a fatiguing amount of weight both the stated parameters maintained a constant increase throughout the entire exercise bout. Using these patterns of response as a guide, stretcher carrying by hand was identified as a fatiguing exercise but when carried by the shoulder harness was non-fatiguing. This investigation, demonstrating the different patterns of cardiovascular response to fatiguing and non-fatiguing contractions(5,9), lends support to the supposition that the pressor response is determined primarily by the muscle group isometrically

contracting at the highest percent MVC during a physical activity.

While investigating fatigue due to isometric contractions, Funderburk, et al.(25) used handgrip contractions of 20, 40, and 60% MVC to produce fatigue. Their data showed that for all three relative tensions, the patterns of response to changes in blood pressure and absolute mean blood pressure (diastolic + 1/3 pulse pressure) obtained were all very similar, but that the rates of change were more abrupt at the higher relative tensions. The higher percentage MVC also caused a larger heart rate increase. The results from this investigation supported the assumption that blood pressure changes resulting from an isometric exercise are due to a reflex stimulation derived from a chemical response, most likely accumulation of potassium ions in the muscle, but that there is a central nervous system stimulus governing the increase in the heart rate.

McCloskey and Stratfield(10) used both animal and human subjects for their investigation of the muscle reflex stimulation to the cardiovascular system during isometric contractions. Using anaesthetized dogs and cats, they stimulated the ventral roots of the hind limbs while observing the blood pressure and heart rate changes.

Blood pressure changes to bilateral hind limb stimulation (ranging from 20-50 mmHg) was greater than the corresponding range (10-35 mmHg), for unilateral stimulation in 13 of the 15 animals.

Using 10 human subjects, the muscle reflex stimulus was studied by comparing the post-exercise occlusion blood pressure values to those obtained during the last 15 seconds of a 1 to 1.5 minute 40% MVC of two different size muscle masses, those producing handgrip and those producing a trigger pull of the little finger. During the handgrip contraction the systolic blood pressure values ranged from 140-190 mmHg while the respective small mass value ranged from 148-192 mmHg. During the 1 to 1.5 minute post-exercise occlusion period, there was an initial drop of the systolic blood pressure, but it remained at a pressure higher than resting throughout the entire period. For each subject, the post-exercise occlusion pressure was higher for handgrip than for the small mass contraction. The authors concluded that, while the results coincided with findings of other investigators that the total pressor response is proportional to the percentage of MVC obtained in the isometrically contracting muscle(2,6,8,9,17), the muscle reflex

component of this response will vary according to the size of the contracting muscle mass.

### Summary

This chapter discussed the test-retest correlation coefficients for repeated MVC and isometric endurance contractions obtained during previous studies. Also presented were thorough reviews of studies which have investigated the blood pressure response to sustained isometric contractions. Basic concepts derived from these studies are: 1) at isometric tensions less than 15% MVC the systolic blood pressure will show an initial increase in response to the contraction, then remain at steady state until the contraction is terminated, 2) at tensions greater than 15% MVC there will be a continuous increase in the systolic blood pressure throughout the entire duration of the isometric contraction, 3) there appears to be a positive correlation between the rate of change in systolic blood pressure and percent MVC, and 4) the systolic blood pressure response is believed to be regulated by the percent maximal voluntary strength at which the muscle is contracting and is independent of the size of the isometrically contracting muscle mass.

The methods used to monitor and characterize the blood pressure responses in the preceding studies varied. Blood pressures were measured either by auscultation or by arterial or aortic catherization. There was no standardized procedure for presenting the results of these studies. Blood pressures were presented as peripheral systolic blood pressures, mean (diastolic + 1/3 pulse pressure) blood pressures, and mean aortic blood pressures. The changes in blood pressure were expressed either as absolute values or increments of change per unit time, but no two studies used the same time intervals for expressing their respective results.

The issue of the reproducibility or reliability of the methods used to monitor blood pressure was not discussed in any of the studies. All of these studies used relatively small numbers of subjects. These studies failed to eliminate or consider the potential contributions of accessory muscle activity to the observed blood pressure response.

# CHAPTER III

## PROCEDURE FOR OBTAINING DATA

### Subjects

Subjects for this study were 21 males between the ages of 20 and 35 years. Potential subjects were screened via a medical history form (Appendix A) which was reviewed by a physician. A resting systolic blood pressure in excess of 130 mmHg excluded an individual from participating in the study.

### Equipment

Recorder. A Beckman eight-channel type R recorder (Figure 1) was used to produce a permanent record with a common time scale of all parameters being measured. The handgrip and index finger adduction dynometers were coupled to the recorder through type 9803 strain gage couplers. The systolic blood pressure signal was recorded using a type 9863A indirect blood pressure coupler. A type 9608A A-C coupler was used to produce the doppler blood flow signals. EMG signals were transformed using type 9852A direct-average EMG couplers. Each of the

Figure [illegible]

Beckman Recorder and Blood Pressure
Monitoring Equipment

couplers was connected to a type 481B preamplifier and a type 482 amplifier(Figure 2).

Blood pressure equipment. The system for measuring systolic blood pressure (Figures 3,4,5 excluding recorder) consisted of (1) the Beckman type R chart recorder, (2) a Beckman 9863A indirect blood pressure coupler, (3) an automated Godart (model 15100A) non-invasive blood pressure monitor, (4) a 23.75 x 5.5 inch sphygmomanometer arm cuff, (5) a Korotkoff sound microphone (a component of a Sphygmostat Model B-350 blood pressure monitoring system from Technical Resources Incorporated), (6) a model 802-A Parker Electronic Laboratory Doppler ultrasonic blood flow monitor, and (7) a Beckman 9608 A A-C coupler.

The Korotkoff microphone was placed over the brachial artery of the non-exercising arm. The Korotkoff sounds, superimposed on the pressure curve tracing from the arm cuff, were recorded on channel 3 of the recorder.

Using Parker Laboratories Aquasonic 100 transmission gel for the coupling medium, the Doppler transducer probe, consisting primarily of two piezoelectric crystals, transmitted the blood flow signals from the radial artery of the non-exercising arm to the electronic control unit and amplifier. The signals were then coupled through the

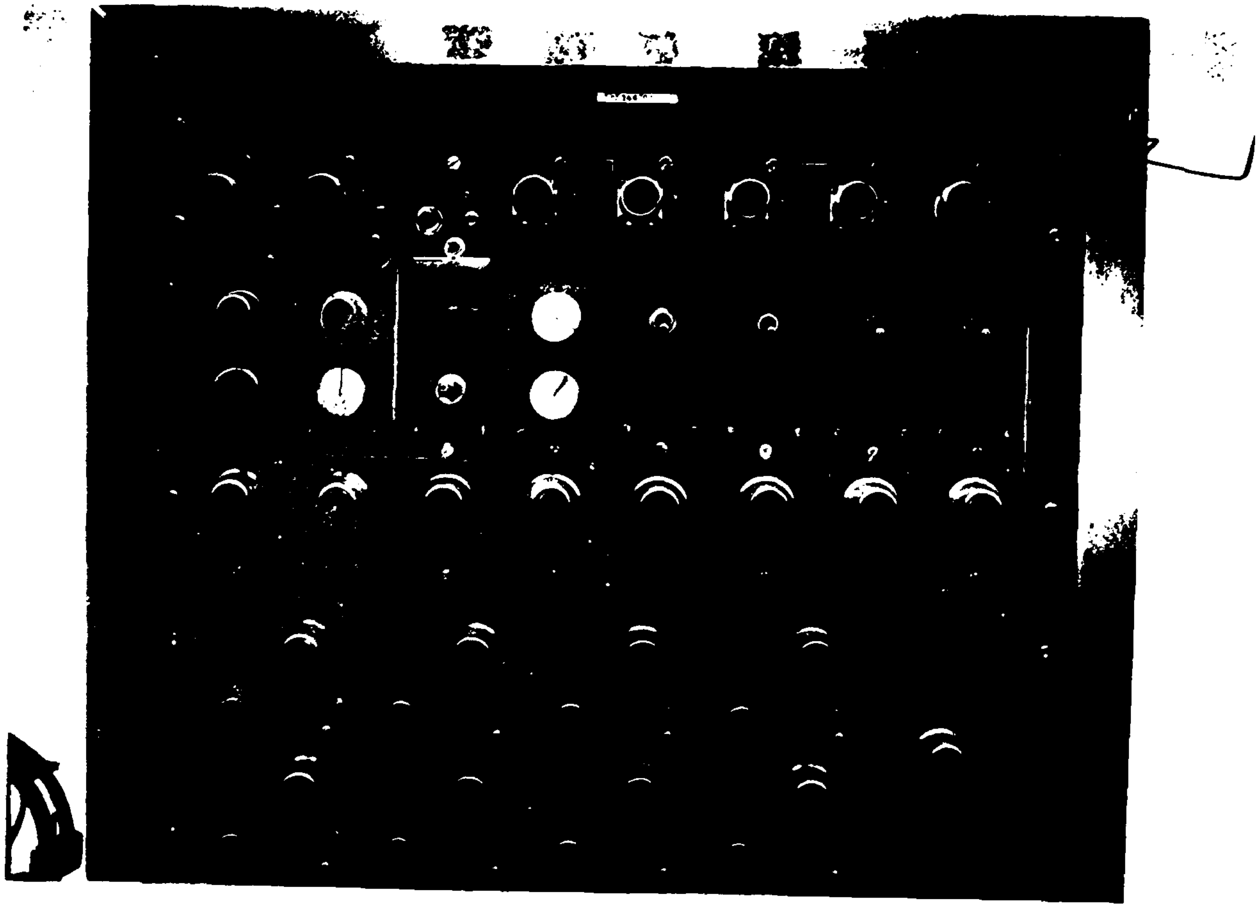

Figure 2

Couplers, Pre-amps, and Amplifiers on the Beckman Recorder

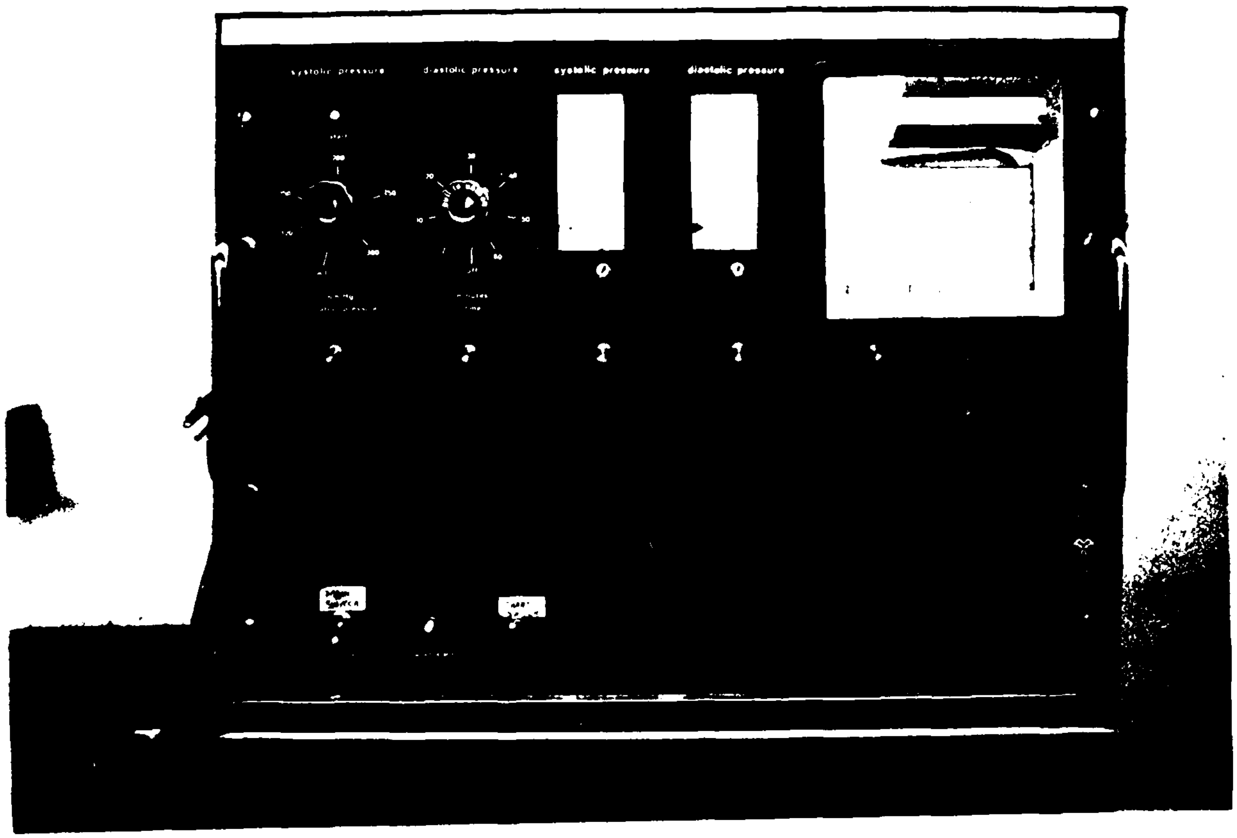


Figure 3

Automated Gelart Blood Pressure Monitor

Figure 4

Korotkoff Microphone and Blood Pressure Cuff

Figure 5

Doppler Blood Flow Monitor

A-C coupler to produce a signal record on channel 4 of the recorder.

Force measuring equipment. The system for measuring the force during index finger adduction (Figure 6) consisted of a platform with stabilizing dowels, padding, strap and an "O" ring force transducer which was coupled to the recorder through a type 9803 Beckman strain gage and recorded on channel 1 of the chart record. A turnbuckle was used between the "O" ring and a stationary post to allow for adjustments needed to standardize the position of the index finger during isometric contractions.

The force produced during the handgrip was monitored using the dynamometer pictured in Figure 7. This force was recorded on channel 2 of the recorder. The "O" ring and finger bar were suspended between the vertical uprights and the distance between the finger bar and the upright to which it was attached was adjustable via the turnbuckle connecting the "O" ring to the distal vertical upright. This was necessary to be able to standardize the position of the fingers during the isometric power grip.

The force transducers were calibrated prior to beginning the study and again each day prior to data collection. The smaller "O" ring was calibrated to

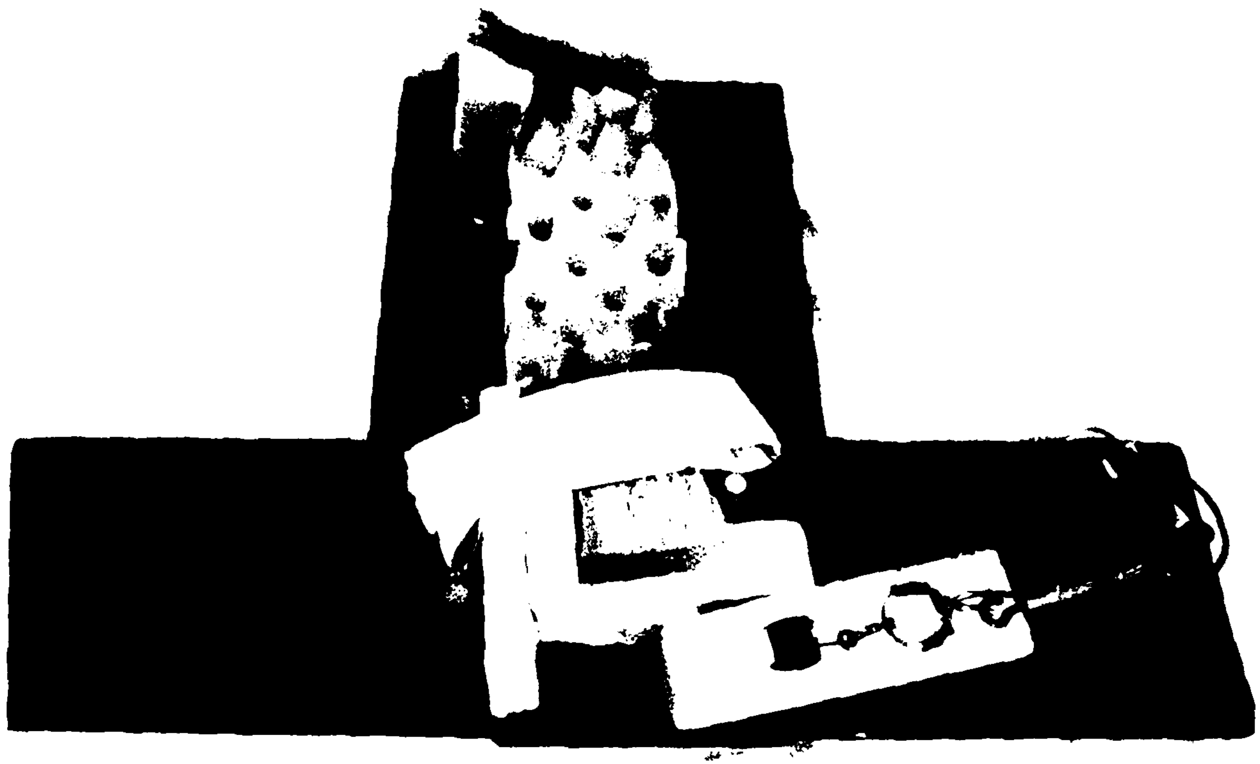

Figure 6

Index Finger Dynamometer

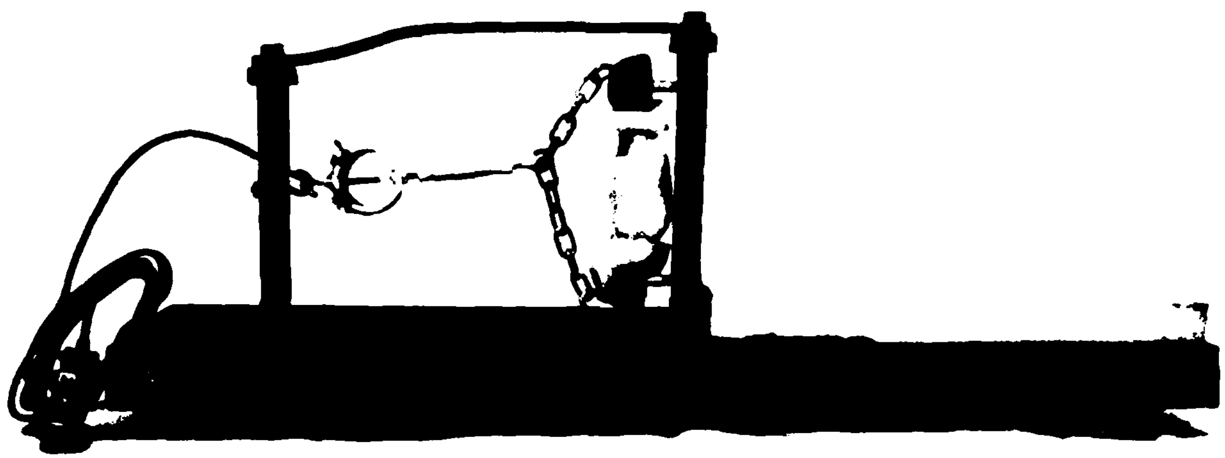

Figure 7

Handgrip Dynamometer

3,000gm (6.61 lbs) and was checked each day using at least three weights to verify its accuracy. The large "O" ring was calibrated to 165.5 lbs and was similarly checked for accuracy daily. All weights used for calibration were verified on scales meeting U.S. standard weights and measures certification. A more detailed description of the calibration procedure and the data resulting from the original calibration procedure for each transducer are found in Appendix B.

EMG equipment. Surface EMG activity was recorded using Beckman #214712 silver/silver chloride electrodes having an electrode size of 11 mm diameter actual pick up diameter of 2.5 mm. Using the 9852A direct-average EMG couplers, the surface EMG activity was recorded on channels 5-8 of the recorder.

## Method

The two exercises selected to represent the different size muscle masses were index finger adduction and handgrip. Although other investigators have used other muscle functions to represent a relatively small muscle mass (9, 10, 26) it was determined through pilot EMG work that index finger adduction was the smallest, most dexterous muscle function that produced the least amount

of extraneous muscle activity that our subjects would be able to perform. This action is performed by the first volar interossei (27,28,29,30). A very functional, natural movement, the handgrip was selected as our relatively large muscle mass. The prime movers and stabilizers of this activity are the flexor digitorium superficialis and profundus, extensor carpi radialis, opponens pollicis, flexor pollicis longus and brevis, abductor pollicis longus, and adductor pollicis (27,28).

Using the estimated 40% MVC for each of the two exercises obtained in the initial session, a 40% MVC fatigue contraction of each exercise was performed during each of two succeeding sessions. Systolic blood pressures were measured prior to the start of the fatigue contractions and approximately every 20 seconds during the contractions. When it was evident that: 1) the subject could no longer hold the designated 40% tension or 2) that the accessory EMG activity was above the 10% cut-off level, the sustained contraction was terminated. Following each 40% fatigue contraction, maximal EMG activity of the accessory muscles and 100% MVC of the isometric contraction were determined. The subjects performed a maximal voluntary strength determination for

each of the two different size muscle groups during the final session.

*Index finger adduction*.The subject was seated in a chair next to the dynamometer with his arm in 30-45° of abduction and 0° flexion and his elbow flexed 90°. The forearm and hand were stabilized in the dynamometer as illustrated in Figure 8, and the finger ring was placed on the index finger such that the proximal edge of the ring was even with the distal interphalangeal (DIP) joint line. The turnbuckle between the "O" ring and the post was then adjusted to position the index finger in 15° of abduction. At the given signal, the subject performed an isometric contraction pulling against the force transducer.

*Handgrip*. The subject was seated in the chair beside the dynamometer such that his arm was in neutral position in the sagital plane, abducted 30-45°, and the elbow flexed 80-90°. He then gripped the finger bar and proximal stabilizing post. The distance between the bar and post was adjusted, following trial contractions, to a distance that the subject said was most comfortable(Figure 9). At the given signal, the subject performed an isometric power handgrip.

*Systolic blood pressure*. The accuracy of the indirect blood pressure monitoring system was tested via

Figure 8

Subject in Index Finger Adduction Dynamometer

Figure 9

Subject in Handgrip Dynamometer

the auscultatory method using a stethoscope and a mercury manometer (Appendix C). Prior to each experimental session, the Beckman pressure transducer system chart output was calibrated with the Beckman anaeroid gauge. Using 200 mmHg as four centimeters deflection on the chart paper, the system was calibrated by progressively increasing and decreasing the cuff pressure through the full range (0 to 200 mmHg).

The first distinct, sharp spike was indicative of blood passing through the artery under the pressure cuff and was therefore judged to represent the systolic blood pressure from the brachial artery. If the first Korotkoff spike was questionable, signals produced from the Doppler blood flow transducer were used to decide which Korctkoff signal was valid. During the initial validation of the blood pressure monitoring system, it was determined that the Korotkoff signal prior to the initial Doppler signal was indicitive of the systolic blood pressure. This criteria was therefore used to determine the systolic blood pressure from the pressure curve if it was questionable which Koretkoff signal to use. The validity of the Doppler-cuff method had been established during a previous study performed in this laboratory(31). The

pressure cuff was calibrated daily prior to data collection.

By using both the Godart pump and a bulb, the pressure in the cuff could be increased rapidly. When this pressure exceeded the systolic blood pressure, as indicated by a loss of the Doppler signals, the pressure was allowed to bleed out through the pump at a slow constant rate. When the pressure reached the systolic blood pressure and less, the Korotkoff signals appeared on the pressure curve and the Doppler signals returned. After Korotkoff and Doppler signals were recorded on the chart paper the remaining pressure was allowed to rapidly bleed out through both the pump and bulb. This procedure was begun prior to the start of the contraction to enable the investigator to get a systolic blood pressure reading during the early phase (the first 5 sec.) of the contraction, and was repeated as often as possible throughout the duration of the contraction. An average of 20 seconds elapsed between blood pressure measurements with an average of seven measurements obtained during the sustained adduction contractions and six during the handgrip contractions.

EMG. Using anatomical and kinesiological information it was determined that the most likely accessory muscle

activity would be recorded by monitoring the skin surface over the bellies of the wrist flexors (flexor carpi radialis), wrist extensors (extensor carpi ulnaris), and the biceps and triceps during index finger adduction and the biceps, triceps, anterior deltoid and pectoralis major during handgrip (27,28, 29,30). The muscles to be monitored were palpated during a manual muscle test (29,32,33) and a 5 cm equilateral triangle was marked over the corresponding areas. Using anatomical landmarks on an average size adult male as reference points, the location of the electrodes was standardizied(Appendix D).

The skin surface where the electrodes were to be placed was abraded with #400 emory cloth. Using Beckman Electrode Electrolyte as the coupling medium, the electrodes were attached with adhesive discs to the skin, and the interelectrode resistance measured. If this was not less than 5000 ohms between any two of the three electrodes, they were removed and the skin reprepared.

During pilot work in preparation for this study simultaneous direct and integrated EMG signals recorded from the same set of surface electrodes demonstrated that only extreme movement of the EMG cables produced a motion artifact that could contaminate the recorded integrated tracing. Similarly it was shown that, under the conditions

existing in the laboratory, the recorded integrated EMG tracings were free of environmental artifacts. There were, however, EKG artifacts present in some of the EMG signals recorded from subjects anterior deltoid and pectoralis major muscles during the study. This was first noticed when the EMG signal from a subject was changed from integrated to direct as a check for contamination of the integrated EMG recording. If the EMG activity from either the anterior deltoid or the pectoralis major was established as the cutoff criteria for the 40%MVC contraction, it was checked, by changing from integrated to direct, for EKG contamination. No EMG tracings contaminated by EKG artifacts were used for establishing the end point of an exercise.

Procedure for Data Acquisition

Prior to data acquisition, each subject was given a subject information form and signed a subject consent form (Appendix A).

At least four exercise sessions were required with each subject. There was at least one, but not more than four, days between each session; sessions were not conducted on weekends. In order to control diurnal

variation sessions were conducted at the same time of day, ±2 hours.

The order of presentation of the two different exercises during the first session with each subject was determined via a random number table. This order of presentation was repeated again during the session in which the third fatigue contractions were performed (session 3). The order of presentation for the session in which the second fatigue contractions were performed (session 2) and for the last session (session 4) was opposite of that during sessions 1 and 3. This reversal of the order of presentation was used to eliminate any bias due to the order of presentation of the exercises.

During all isometric contractions, the subjects were given verbal motivation by the investigator to produce maximal tension and to sustain the endurance contractions as long as possible.

Systolic blood pressure measurements were taken only during sessions 2 and 3.

The subjects were not allowed to observe the chart needle deflection from the dynamometers during MVC determinations, however, during the 40% MVC the subjects monitored their tension by observing the needle deflections. The subjects were instructed to do their

best to maintain a straight line at a predetermined level indicated by a mark on the chart paper. A mark was made on the appropriate channel of the chart paper indicating the 40% MVC of the respective exercise, and the subject was instructed, as the chart paper advanced, to draw as straight a line as possible at this level. Even though the subject was monitoring the tension himself, the investigator was continually giving verbal feedback to keep the tension as constant as possible.

Session 1. The subject was set up in the appropriate dynamometer and maximal isometric tension was determined. For this study, maximal isometric tension had been defined as the mean value of three brief isometric contraction each of 3 seconds duration and with 1 minute rest between contractions. After allowing at least a 5 minute rest, the subject was set up in the other dynamometer and performed a maximal isometric tension determination of the second exercise. EMG electrode sites were marked, prepared, and the surface electrodes were attached, after which the interelectrode resistance was measured. An appropriate sensitivity setting was then determined for each of the four muscle groups being monitored. The subject then performed a 40% MVC, based on the MVC just determined, of the second exercise. This 40% contraction

was held until either 1) the subject could no longer maintain the contraction, or 2) the integrated EMG tracing of any of the four areas being monitored exceeded 10mm from its baseline. Since maximal needle deflection possible for an EMG record was 50 mm, the width of a channel on the chart paper used, if the needle was deflected 10 mm (20% of the channel width) it would have greatly exceeded the maximum accessory muscle EMG allowed for this study. A minimum of 3 minutes was allowed for rest, after which a maximal muscle contraction for each of the accessory muscle groups being monitored for EMG activity was performed. The integrated EMG activity recorded during this maximal contraction was the 100% value upon which the 10% cut-off level for the accessory muscle activity was based. The electrode positions for the other two muscle areas to be monitored were prepared, the appropriate EMG electrodes were moved, and the interelectrode resistance measured. The subject was then repositioned in the initial dynamometer and performed a 40% MVC contraction based on the respective MVC determined at the first of the session. Again, following at least a 3 minute rest, the integrated EMG activity of the monitored muscle groups was recorded during a maximal contraction of the respective accessory muscle groups.

After removal of the electrodes and changing the dynamometers, which allowed at least a 5 minute rest, MVC determinations were again performed for both exercises, in reverse order of that during the first part of the session.

The 40% MVC values to be used for the fatigue contractions during sessions 2 and 3 were calculated from the two 100% MVC trials performed during session 1. If the endurance time of a sustained contraction performed during session 1 was greater than or equal to 150 seconds, the higher of the two respective 100% MVC values was used to calculate the 40% MVC value. If the endurance time of the sustained contraction was less than or equal to 45 seconds, the lower 100% MVC value was used. This protocol was based on studies which indicated a range of 45 to 150 seconds for a sustained 40% MVC(2,9,10,11,25,34). With adduction, the smaller of the two 100% MVC values was used for three of the 21 subjects. The larger of the two MVC values was used for all 40% calculations for handgrip.

No blood pressures were taken during this session; it was used to acquaint the subjects with the equipment and what to expect during the following sessions.

Session 2. Using marks made during the initial session, the EMG electrodes were positioned for the

appropriate exercise. Next the blood pressure monitoring equipment was attached and a resting systolic blood pressure was recorded. The interelectrode resistance was then measured and an appropriate sensitivity for the EMG was selected. The subject was positioned in the appropriate dynamometer(Figure 10). Systolic blood pressure was monitored until it was within 10 mmHg of the systolic blood pressure taken previously, this being the criteria used to define a stable, resting systolic blood pressure. After a resting systolic blood pressure value had been established, the subject performed a 40% MVC based on the respective 100% MVC determined in session 1. When the subject could no longer maintain the proper tension or when any one of the EMG recordings exceeded 10mm deflection on the chart paper, the contraction was terminated. EMG activity during a maximal contraction of the monitored muscle groups was obtained as in session 1.

The appropriate EMG electrodes were changed and the interelectrode resistance was measured between these electrodes. The subject was then positioned in the second dynamometer. When the systolic blood pressure was stable, within 10 mmHg of the initial systolic blood pressure recorded during the first part of the session, the subject performed a sustained 40% MVC of the second exercise. The

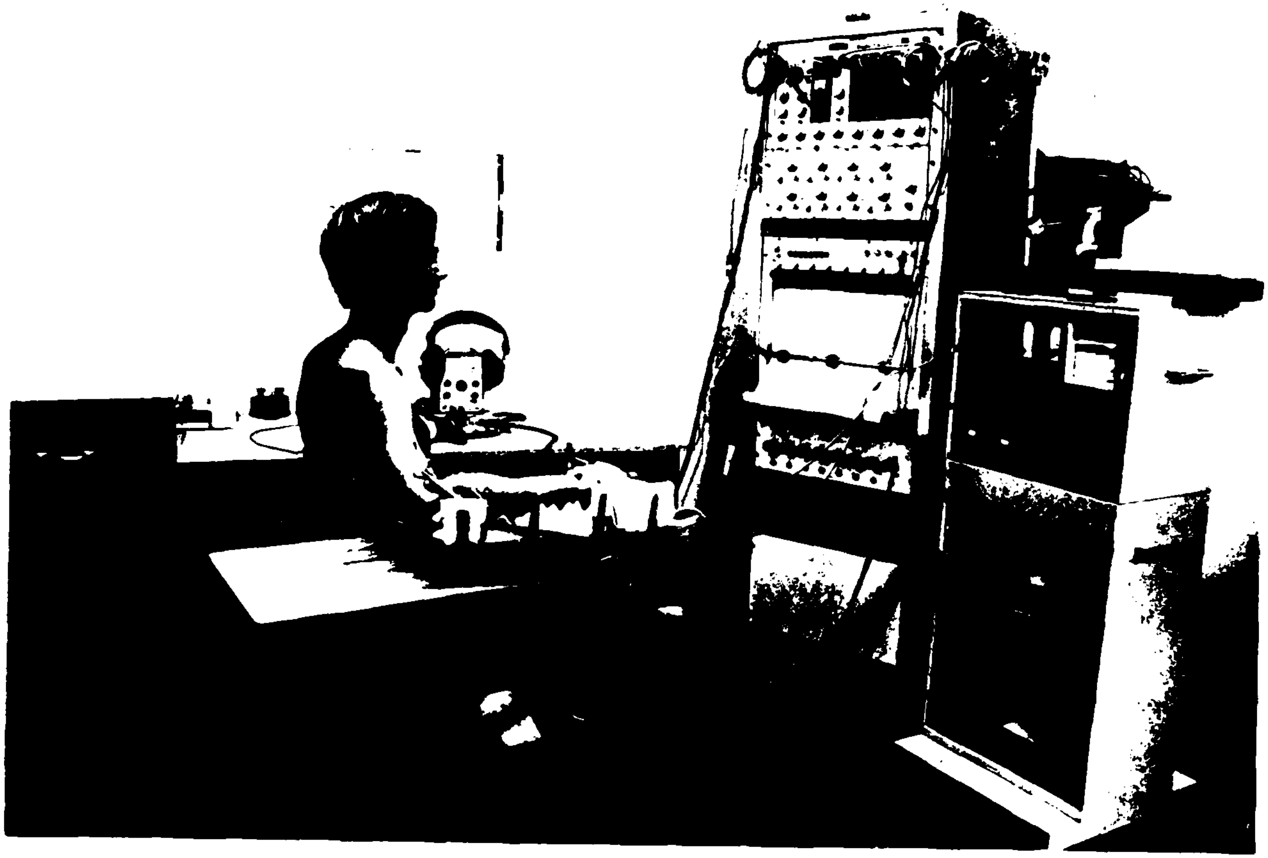

Figure 10

Subject Ready to Perform Sustained 40% Index Finger Adduction Contraction

exercise was terminated using the criteria previously stated. Maximal EMG activity was recorded in the same manner as before.

Session 3. The procedure for data acquisition during session 3 was identical to that of session 2, except that the order of presentation of the exercises was reversed.

Session 4. The order of presentation of the exercises was the same as that in session 3. The subject was positioned in the appropriate dynamometer and 100% MVC was determined. Following at least a 5 minute rest, 100% MVC was determined for the second exercise.

## Procedure for Data Reduction

Using a paper speed of .2 cm/sec during the first and fourth sessions and a speed of .5 cm/sec during the second and third sessions, permanent records were produced during each contraction. Appendix E illustrates a portion of a chart record produced by a subject during session 2.

MVC. The first three 100% MVC values within a 10mm range (1.3 pounds for index finger adduction and 28 pounds for handgrip) were averaged to calculate the value for an MVC determination. If two contractions were within this range and the other was greatly increased or decreased, additional contractions were performed. Some subjects

actually performed as many as seven brief maximal contractions before three values within this 10mm range were obtained. There were 29 out of a total of 104 index finger MVC determinations when more than three brief contractions were performed for an index finger adduction MVC determination. In 11 of these 29 instances the three brief tensions included the highest of the recorded values. In the other 18 instances the three brief tensions averaged for the MVC determination did not include the highest of the recorded tensions. In 13 of these 18 times the highest brief contraction value recorded (but not used) was greater than the highest of the five MVC determinations for the respective subject. Although there were 13 separate MVC determinations of concern, they involved only seven different subjects. Similarly, there were eight instances when more than three brief contractions were taken for a handgrip MVC determination. Of these eight, there were six instances when the three brief contraction values averaged for the MVC determination included the highest of the recorded tensions. The remaining two instances did not use the highest recorded tension for the respective MVC determination. In both of these cases, though, the highest brief contraction value recorded (but not used)

was less than the highest of the respective subject's five MVC determinations.

<u>40% MVC tension</u>. When the tension during a 40% MVC contraction was decreased more than 10% below the calculated 40% tension for longer than 5 seconds the chart record was marked to indicate the termination of the experimental contraction.

<u>EMG activity</u>. The 10% allowable accessory muscle EMG activity was determined for each muscle group for each session based on the 100% activity recorded for the respective groups during the respective session. When the EMG activity recorded during the 40% contraction exceeded this 10% level, the chart record was marked to indicate the termination of the experimental contraction.

<u>Duration of contraction</u>. The duration of a contraction was determined by calculating the time interval between the onset and termination, due to either decreased tension or excessive EMG activity, of the contraction using the time interval marks produced by the recorder.

<u>Systolic blood pressure</u>. The first distinct, sharp spike produced by the Korotkoff microphone, as compared to artifacts, on the decreasing pressure curve was interpreted as the systolic blood pressure. If there was

not a clear distinction between the artifacts and the first sharp spike, the Doppler signal was used, as described previously, to interpret the systolic blood pressure. Only systolic blood pressures recorded prior to the cut off time as determined by either the decreased level of isometric tension or excessive EMG activity were used for data reduction. Repeated systolic blood pressure measurements were obtained during the sustained 40% MVC contractions. For both the index finger adduction and handgrip contractions the first exercising systolic blood pressure measurement was taken within the first 7 seconds of the sustained contraction. Individual regression lines, in the form y = mx + b, of systolic blood pressure versus time were calculated for each sustained contraction performed by each subject during sessions 2 and 3. These regression lines were considered the criterion measures of the systolic blood pressure responses to the sustained 40% MVC contractions.

Methods of Statistical Analysis

The Statistical Analysis System (SAS) library programs GLM, ANOVA, and MEANS were utilized for the statistical analyses. The .05 level of significance was chosen for this study. Means and standard deviations were

calculated for the 100% MVC determinations, resting systolic blood pressure measurements, and endurance times. Means and standard error of the means were calculated for the slopes and intercepts of the regression lines representing the mean systolic blood pressure response to each repetition of each different size muscle mass and the grand mean response to each different size muscle mass.

Reproducibility. The degree of reproducibility of repeated measurements was established by testing how well the values correlated and the significance of the difference between the values for repeated measurements. The correlation was determined by calculating Pearson product-moment correlation coefficients (r). The significance of differences was tested by either an analysis of variance or a paired t-test. Correlation coefficients were calculated for the values of the five MVC determinations for each of the two different size muscle groups, the resting systolic blood pressures measured at the start of sessions 2 and 3, the endurance times for the two sustained contractions of each different size muscle group performed by each subject, and the slopes and intercepts of the regression lines representing the systolic blood pressure responses to the two sustained contractions performed by each subject of the two

different size muscle groups. Analyses of variance procedures were perfcrmed to test the significance of the differences between the five MVC determination values for the two different size muscle groups. Duncan's multirange tests were performed on the five mean MVC determinaticn values for each different size muscle group to determine where the significant differences existed. The significance of the difference between the endurance times for the two sustained contractions of each size muscle group performed by each subject was also tested via an analysis of variance. Paired t-tests were performed to test the significance of the difference between paired resting systolic blocd pressure measurements and paired slopes and paired intercepts of the two sustained contractions performed by each subject for each size muscle group.

Inter-variable relationships. Simple linear regression was performed cn the exercising systolic blood pressure measurements and the corresponding times at which the measurements were taken to characterize a subject's systolic blool pressure response to a sustained isometric contraction. Individual and combined correlation coefficients were ccmputed for the exercising systolic

blood pressure measurements versus time for the sustained contractions(35).

Student's t-tests were performed on the slopes and intercepts of the regression lines representing the mean response of the 21 subjects to each sustained contraction of the two different size muscle groups and the mean response of the 21 subjects to each of the two different size muscle groups to test the significance of the slopes and intercepts relative to 0 slope and 0 intercept.

Inter-exercise comparisons. An analysis of variance was performed to test the significance of the difference between the slopes and intercepts of the regression lines representing the mean response of the 21 subjects to the sustained contractions of each of the two different size muscle groups.

# CHAPTER IV

## RESULTS

This chapter presents the results of the analyses performed on the collected data.

### Strength Measurements

__Adduction.__ Individual maximal strength values for index finger adduction and the mean and standard deviation for each trial are given in Table 1. The degree of within subject reproducibility was established using the Pearson product-moment correlation coefficient (r). The r values derived from the correlation between any two mean values of the five maximal strength determinations are presented in Table 2. The r value for max 1 vs max 2 (r = .842) illustrates the within day reproducibility. All other r values illustrate between day comparisons. These values ranged from r = .336 (max 1 vs max 4) to r = .709 (max 2 vs max 3).

An analysis of variance procedure was performed to determine if there were significant differences between the five index finger MVC determinations performed by each

Table 1

Maximal Voluntary Strength for Index Finger Adduction (lbs)

| Subject | Trial 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 2.40 | * | 2.60 | 3.19 | 4.73 |
| 2 | 4.11 | 3.44 | 2.48 | 2.70 | 3.08 |
| 3 | 2.31 | 1.87 | 2.42 | 4.48 | 4.58 |
| 4 | 1.65 | 1.96 | 3.15 | 4.37 | 2.55 |
| 5 | 3.61 | 2.87 | 3.58 | 3.88 | 4.18 |
| 6 | 3.33 | 2.60 | 2.51 | 3.00 | 3.65 |
| 7 | 2.54 | 2.49 | 2.89 | 2.97 | 2.82 |
| 8 | 3.86 | 3.96 | 4.40 | 5.35 | 4.38 |
| 9 | 4.68 | 5.39 | 4.14 | 5.42 | 4.76 |
| 10 | 4.18 | 4.27 | 4.68 | 4.57 | 4.57 |
| 11 | 3.42 | 3.33 | 3.92 | 3.11 | 3.03 |
| 12 | 3.52 | 3.81 | 4.79 | 3.85 | 3.39 |
| 13 | 3.52 | 3.84 | 3.31 | 2.45 | 3.11 |
| 14 | 3.19 | 3.85 | 5.46 | 4.65 | 3.50 |
| 15 | 4.05 | 4.38 | 3.91 | 4.76 | 3.22 |
| 16 | 3.88 | 5.69 | 5.90 | 5.83 | 5.97 |
| 17 | 4.08 | 3.39 | 4.21 | 3.11 | 2.97 |
| 18 | 3.74 | 3.99 | 4.86 | 5.08 | 3.85 |
| 19 | 2.67 | 1.54 | 1.90 | 1.83 | 1.93 |
| 20 | 3.15 | 3.33 | 3.72 | 4.55 | 5.19 |
| 21 | 4.02 | 3.00 | 3.72 | 4.55 | 4.53 |
| Mean | 3.41 | 3.35 | 3.75 | 3.97 | 3.81 |
| S.D. | .78 | .94 | 1.06 | 1.08 | .99 |

*missing data

Table 2

Reproducibility of Maximum Strength Determinations for Index Finger Adduction: Pearson Product Moment Correlation Coefficient (r) for Comparison Between Trials

| | Max 2 | Max 3 | Max 4 | Max 5 |
|---|---|---|---|---|
| Max 1 | .842*<br>(.0001) ** | .534<br>(.0127) | .336<br>(.1363) | .337<br>(.1355) |
| Max 2 | | .709<br>(.0005) | .570<br>(.0087) | .441<br>(.0515) |
| Max 3 | | | .701<br>(.0004) | .428<br>(.0527) |
| Max 4 | | | | .684<br>(.0006) |

*within day correlation; all others are between day correlations
**probability of getting a larger r value if no correlation exists

subject. A calculated value of F = 3.39 indicated that at the .05 level of significance, there was a significant difference between the values. A follow-up to the analysis of variance, the Duncan's multiple range test, indicated that there was no significant difference between the mean values for Group C (max 1,2,3), Group B (max 2,3,5), and Group A (max 3,5,4). There was a general trend of increasing strength with successive MVC determinations, although there was not a significant difference between any two successive trials. This includes the within day determinations (trials number 1 and 2) and between day trials (trials number 2 and 3, 3 and 4, and 4 and 5). The significant differences were between trials 1 and 4, 1 and 5, and 2 and 4. Tables 3 and 4 display the results of the analysis of variance and the Duncan's test, respectively.

Handgrip. The individual values, means, and standard deviations for the handgrip maximal strength trials are shown in Table 5. The Pearson correlation coefficient (r) was again used to demonstrate the degree of within subject reproducibility. The within day reproducibility for the handgrip MVC determinations was r = .843 (max 1 vs max 2). The between day correlation coefficients ranged from r = .448 (max 3 vs max 5) to r = .780 (max 2 vs max 5), Table 6. An analysis of variance performed on the

Table 3

Summary of Analysis of Variance for Comparison Between Trials of Maximum Strength Determinations for Index Finger Adduction

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | F* | p** |
|---|---|---|---|---|---|
| Trials (within) | 4 | 5.92 | 1.480 | 3.39 | .0129 |
| Subjects (between) | 20 | 60.25 | 3.012 | 6.91 | .0001 |
| Error | 79 | 34.44 | 0.436 | | |
| Total | 103 | 100.61 | | | |

*F for .05 level (4,79 D.F.) = 2.50
F for .05 level (20,79 D.F.) = 1.72
**p = probability of getting a larger F value

Table 4

Duncan's Multiple Range Test for Differences Between Mean Values for Trial One to Five for Maximal Strength for Index Finger Adduction

| Grouping* | | | Mean (lbs) | Number of Subjects | Trial Number |
|---|---|---|---|---|---|
| | | A | 3.97 | 21 | 4 |
| | B | A | 3.81 | 21 | 5 |
| C | B | A | 3.75 | 21 | 3 |
| C | B | | 3.41 | 21 | 2 |
| C | | | 3.35 | 20 | 1 |

*means with the same letter are not significantly different at the .05 level

Table 5

Maximal Voluntary Strength for Handgrip (lbs)

| Subject | Trial 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 104.6 | * | 129.4 | 92.2 | 97.8 |
| 2 | 140.6 | 127.2 | 131.4 | 114.6 | 121.6 |
| 3 | 157.0 | 153.2 | 141.2 | 145.4 | 157.1 |
| 4 | 113.2 | 117.7 | 107.1 | 116.0 | 111.8 |
| 5 | 134.5 | 131.4 | 132.3 | 125.8 | 135.0 |
| 6 | 155.2 | 131.4 | 137.0 | 130.9 | 111.3 |
| 7 | 108.4 | 100.6 | 110.4 | 91.3 | 119.3 |
| 8 | 103.4 | 104.8 | 104.8 | 116.5 | 116.9 |
| 9 | 119.1 | 126.1 | 112.3 | 133.7 | 130.5 |
| 10 | 102.0 | 87.5 | 106.7 | 98.7 | 103.9 |
| 11 | 85.6 | 93.6 | 99.6 | 98.7 | 101.4 |
| 12 | 130.5 | 111.8 | 104.8 | 98.7 | 130.0 |
| 13 | 134.0 | 120.6 | 98.6 | 129.5 | 135.9 |
| 14 | 120.2 | 101.5 | 98.1 | 95.0 | 95.0 |
| 15 | 110.4 | 122.5 | 127.7 | 160.3 | 137.9 |
| 16 | 114.6 | 123.5 | 123.5 | 130.9 | 136.1 |
| 17 | 99.7 | 89.4 | 81.9 | 93.1 | 95.9 |
| 18 | 137.9 | 128.6 | 135.6 | 146.8 | 139.3 |
| 19 | 113.2 | 97.2 | 116.8 | 130.5 | 93.6 |
| 20 | 100.6 | 94.1 | 117.4 | 139.3 | 106.2 |
| 21 | 97.8 | 100.6 | 106.7 | 106.2 | 133.3 |
| Mean | 118.2 | 113.2 | 115.1 | 119.1 | 119.5 |
| S.D. | 19.3 | 17.6 | 16.1 | 20.4 | 18.1 |

*missing data

Table 6

Reproducibility of Maximum Strength Determinations for Handgrip: Pearson Product Moment Correlation Coefficient (r) for Comparison Between Trials

| | Max 2 | Max 3 | Max 4 | Max 5 |
|---|---|---|---|---|
| Max 1 | .843*<br>(.0001) ** | .590<br>(.0049) | .459<br>(.0362) | .534<br>(.0127) |
| Max 2 | | .746<br>(.0002) | .647<br>(.0021) | .780<br>(.0001) |
| Max 3 | | | .597<br>(.0043) | .448<br>(.0418) |
| Max 4 | | | | .602<br>(.0039) |

*within day correlation; all others are between day correlations
**probability of getting a larger r value if no correlation exists

handgrip MVC determinations demonstrated no significant differences between a subject's five MVC determination values ($F = 1.18$). This was also verified by the Duncan's multirange test. Tables 7 and 8 show the results of these two statistical procedures.

Resting Systolic Blood Pressure

Table 9 gives the values and the correlation coefficient for the resting systolic blood pressures taken prior to the 40% fatigue contractions performed during sessions 2 and 3. A paired t-test resulted in a calculated $t = -1.50$, indicating no significant difference existed between the corresponding pairs of resting systolic blood pressure values.

Endurance Times

Adduction. The two endurance times obtained for each subject for the sustained index finger adduction contractions are shown in Table 10. The within subject reproducibility was demonstrated using the Pearson correlation coefficient, $r = .59$. Although the second sustained contraction was usually of longer duration than the first, an analysis of variance demonstrated that there

Table 7

Summary of Analysis of Variance for Comparison Between Trials of Maximum Strength Determinations for Handgrip

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | F* | p** |
|---|---|---|---|---|---|
| Trials (within) | 4 | 624.96 | 156.24 | 1.18 | .3278 |
| Subjects (between) | 20 | 22920.01 | 1146.0 | 8.63 | .0001 |
| Error | 79 | 10494.42 | 132.84 | | |
| Total | 103 | 34039.39 | | | |

*F for .05 level (4,79 D.F.) = 2.50
F for .05 level (20,79 D.F.) = 1.72
**probability of getting a larger F value

Table 8

Duncan's Multiple Range Test for Differences Between Mean Values for Trial One to Five for Maximal Strength for Handgrip

| Grouping* | Mean (lbs) | Number of Subjects | Trial Number |
|---|---|---|---|
| A | 119.51 | 21 | 5 |
| A | 119.06 | 21 | 4 |
| A | 118.21 | 21 | 1 |
| A | 115.06 | 21 | 3 |
| A | 113.17 | 20 | 2 |

*means with the same letter are not significantly different at the .05 level

Table 9

Resting Systolic Blood Pressures (mmHg) and Correlation Coefficient Taken at the Beginning of Sessions 2 and 3

| Subject | Session 2 | Session 3 |
|---|---|---|
| 1 | 132.5 | 127.5 |
| 2 | 110.0 | 117.5 |
| 3 | 117.5 | 127.5 |
| 4 | 130.0 | 122.5 |
| 5 | 110.0 | 120.0 |
| 6 | 117.5 | 112.5 |
| 7 | 127.5 | 127.5 |
| 8 | 125.0 | 137.5 |
| 9 | 117.5 | 122.5 |
| 10 | 105.0 | 112.5 |
| 11 | 117.5 | 125.0 |
| 12 | 107.5 | 117.0 |
| 13 | 125.0 | 112.5 |
| 14 | 120.0 | 127.5 |
| 15 | 115.0 | 125.0 |
| 16 | 112.5 | 107.5 |
| 17 | 110.0 | 105.0 |
| 18 | 140.0 | 135.0 |
| 19 | 122.5 | 122.5 |
| 20 | 122.5 | 127.5 |
| 21 | 102.5 | 105.0 |
| Mean | 118.5 | 120.8 |
| S.D. | 9.5 | 9.1 |

$r = .695$
$p^* < .001$

*probability of getting a larger r value if no correlation exists

Table 10

Endurance Times and Correlation Coefficient for 40% MVC for Index Finger Adduction (sec)

| Subject | Session 2 | Session 3 |
|---|---|---|
| 1 | 113.0 | 195.4 |
| 2 | 111.4 | 151.6 |
| 3 | 158.4 | 189.0 |
| 4 | 146.6 | 119.2 |
| 5 | 102.6 | 107.2 |
| 6 | 131.0 | 149.0 |
| 7 | 131.8 | 176.0 |
| 8 | 120.8 | 109.2 |
| 9 | 86.0 | 67.0 |
| 10 | 75.8 | 129.6 |
| 11 | 191.6 | 172.2 |
| 12 | 120.0 | 162.2 |
| 13 | 145.0 | 146.8 |
| 14 | 80.6 | 72.6 |
| 15 | 121.2 | 123.0 |
| 16 | 151.6 | 185.8 |
| 17 | 97.6 | 148.0 |
| 18 | 164.0 | 173.4 |
| 19 | 121.0 | 105.8 |
| 20 | 181.2 | 151.2 |
| 21 | 177.2 | 179.6 |
| Mean | 129.9 | 143.5 |
| S.D. | 32.9 | 36.9 |

$r = .59$

$p^* < .005$

*probability of getting a larger r value if no correlation exists

was no significant difference between the two durations at the .05 level, Table 11.

Handgrip. The endurance times obtained for the sustained handgrip contractions are shown in Table 12. An $r = .65$ was calculated for repeated measurements of this variable. As with adduction, the second sustained handgrip time was generally longer than the first. In contrast to the adduction times, though, the analysis of variance indicated a significant difference between a subject's two handgrip endurance times did exist(Table 13).

## Slopes and Intercepts

Using time (recorded in seconds) as the abscissa and systolic blood pressure (recorded in mmHg) as the ordinate, regression lines representing the blood pressure response of each subject to each sustained contraction were calculated using the regression formula $y = mx + b$ where $y$ = systolic blood pressure, $m$ = slope, $x$ = time, and $b$ = y intercept(Figures 11,12, and 13). An average of seven systolic blood pressure measurements (±2) with a 20 second interval between repeated measurements was obtained for index finger adduction. Similarly, an average of six measurements (±2) with an interval of 19

Table 11

Summary of Analysis of Variance for
Comparison of Endurance Times for
40% MVC Index Finger Adduction

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | F* | p** |
|---|---|---|---|---|---|
| Repetition (within) | 1 | 752.69 | 752.69 | 1.40 | .2499 |
| Subjects (between) | 20 | 39302.14 | 196.61 | 3.67 | .0027 |
| Error | 20 | 10719.49 | 535.97 | | |
| Total | 41 | 50774.32 | | | |

*F for .05 level (1,20 D.F.) = 4.35
F for .05 level (20,20 D.F.) = 2.12
**probability of getting a larger F value

Table 12

Endurance Times and Correlation
Coefficient for 40% MVC
for Handgrip (sec)

| Subject | Session 2 | Session 3 |
|---|---|---|
| 1 | 49.8 | 92.2 |
| 2 | 77.4 | 100.4 |
| 3 | 105.0 | 100.2 |
| 4 | 182.8 | 241.4 |
| 5 | 102.4 | 159.0 |
| 6 | 88.6 | 105.8 |
| 7 | 103.8 | 105.8 |
| 8 | 152.2 | 182.8 |
| 9 | 96.6 | 99.6 |
| 10 | 122.4 | 169.6 |
| 11 | 166.0 | 140.0 |
| 12 | 131.6 | 120.0 |
| 13 | 124.6 | 169.8 |
| 14 | 68.4 | 82.2 |
| 15 | 147.2 | 247.8 |
| 16 | 160.2 | 140.4 |
| 17 | 119.0 | 90.4 |
| 18 | 140.8 | 127.8 |
| 19 | 65.2 | 158.2 |
| 20 | 93.0 | 139.2 |
| 21 | 99.2 | 133.8 |
| Mean | 114.1 | 138.4 |
| S.D. | 35.5 | 45.8 |

$r = .65$
$p^* < .002$

*probability of getting a larger r value if no correlation exists

Table 13

Summary of Analysis of Variance for
Comparison of Endurance Times for
40% MVC for Handgrip

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | F* | p** |
|---|---|---|---|---|---|
| Repetition (within) | 1 | 5721.33 | 5721.33 | 8.65 | .0081 |
| Subjects (between) | 20 | 55698.78 | 2784.94 | 4.21 | .0011 |
| Error | 20 | 13231.09 | 661.55 | | |
| Total | 41 | 74651.20 | | | |

*F for .05 level (1,20 D.F.) = 4.35
F for .05 level (20,20 D.F.) = 2.12
**probability of getting a larger F value

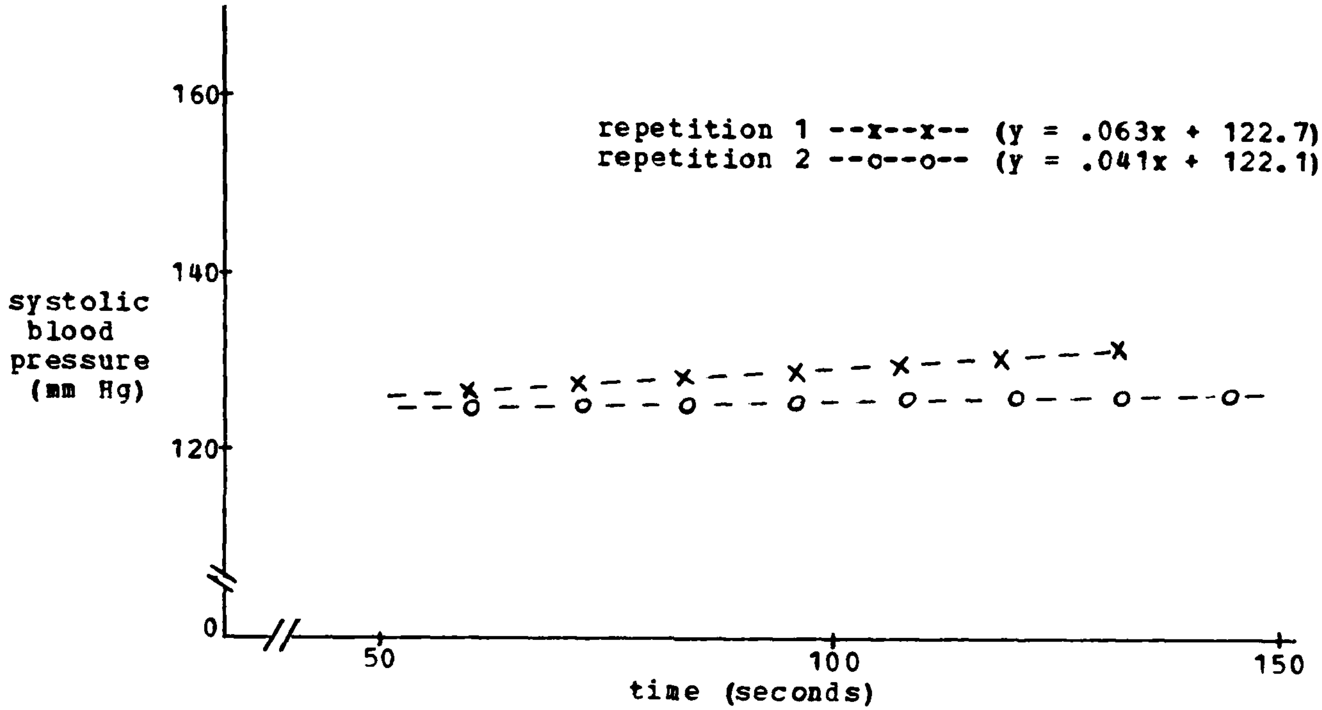


Figure 11

Regression Lines Representing Systolic Blood Pressure Responses To Sustained 40% MVC Index Finger Adduction Contractions

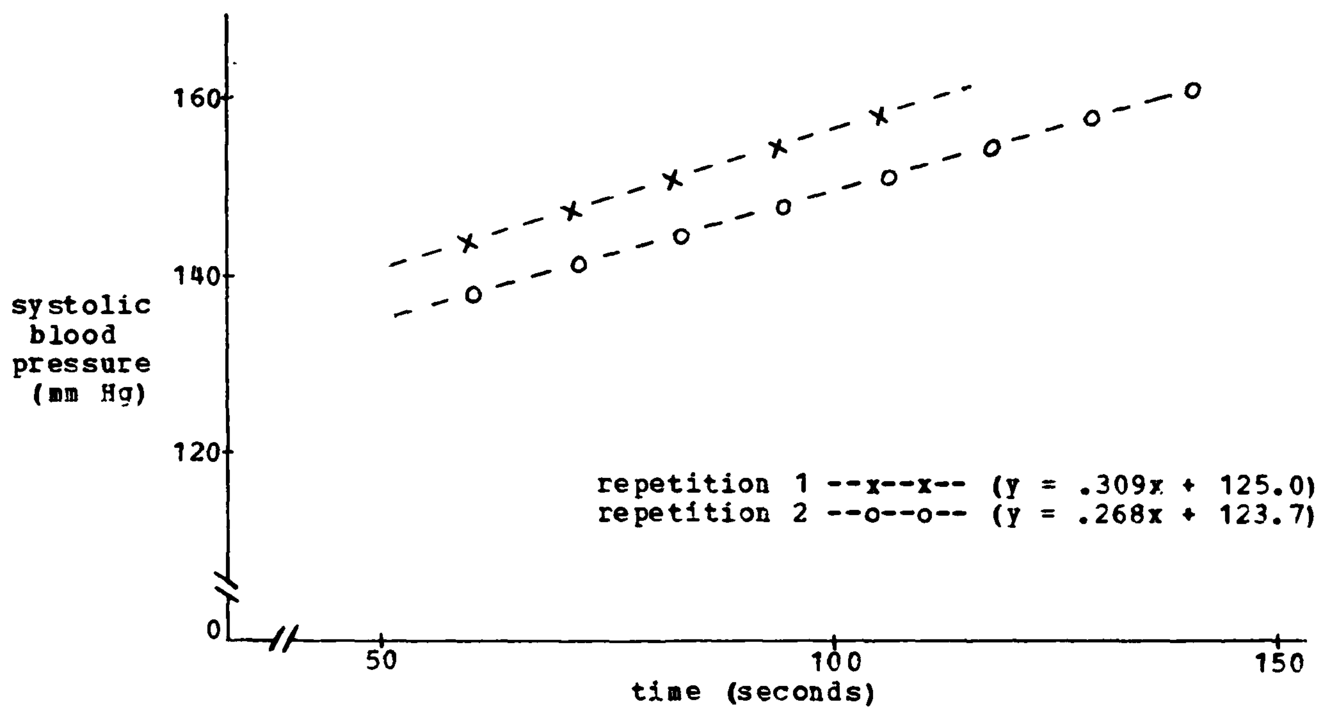


Figure 12

Regression Lines Representing Systolic Blood Pressure Responses tc Sustained 40% MVC Handgrip Contractions

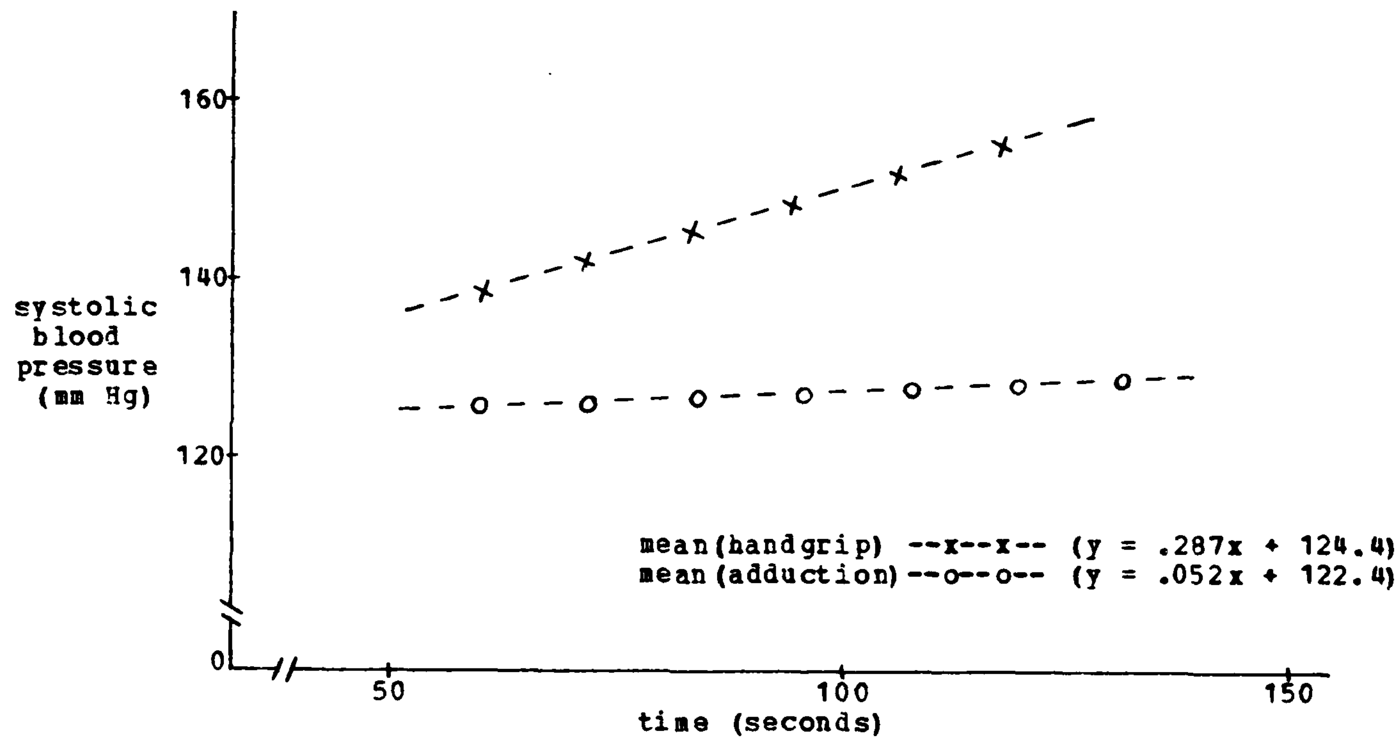


Figure 13

Regression Lines Representing Mean Systolic Blood Pressure Responses to Sustained 40% MVC Index Finger Adduction and Handgrip Contractions

seconds was obtained during the sustained handgrip contractions.

Adduction. A t-test to determine if a significant increase above the resting systolic blood pressure occurred was performed on the slopes and the intercepts of the three regression lines (mean response-repetition 1, mean response-repetition 2, and mean response-index finger adduction) for index finger adduction, Table 14. All three slopes and intercepts were significantly different from 0. The slopes being different from 0 indicated significant blood pressure increases occurred.

Individual and combined correlation coefficients for the systolic blood pressure measurements vs time (the exercising blood pressure measurements) were calculated, Appendix F, Table F-1. The average correlation coefficient for the systolic blood pressure measurements with time during the sustained index finger adduction contractions was $r = .59$ ($p < .001$). Although the combined correlation was seemingly low, there was a correlation between increasing systolic blood pressure and time during the sustained index finger adduction contractions.

Correlation coefficients, indicative of the reproducibility, for the slopes and intercepts of the regression lines representing the mean systolic blood

Table 14

Results of Student's t-Test Performed on Slopes and Intercepts of Regression Lines Representing Systolic Blood Pressure Responses to 40%MVC Index Finger Adduction Contractions (testing null Hypothesis $H_o: \mu=0$)

| | | Mean | Standard Error of the Mean | t* | p** | Degrees of Freedom |
|---|---|---|---|---|---|---|
| Session 2 | Slope | .063 | .019 | 6.90 | .0001 | 20 |
| | Intercept | 122.65 | 2.12 | 57.92 | .0001 | 20 |
| Session 3 | Slope | .041 | .015 | 2.56 | .0187 | 20 |
| | Intercept | 122.11 | 1.57 | 77.90 | .0001 | 20 |
| Mean | Slope | .052 | .009 | 8.66 | .0001 | 20 |
| | Intercept | 122.38 | 1.21 | 101.42 | .0001 | 20 |

*t for .05 level (20 D.F.) = 1.72
**probability of getting a larger t value

pressure responses to the two endurance contractions for index finger adduction were r = .198 and r = .706, respectively. Calculated t values of t = 1.3 and t = .36, for slopes and intercepts respectively, indicated no significant differences between corresponding pairs of regression lines representing the two sustained index finger contractions performed by each subject. Even though a subject's blood pressure response to the sustained adduction contractions was not highly reproducible, as indicated by the low correlation coefficient for the slopes of the regression lines (r = .198), there was not a significant difference between a subject's two responses.

Handgrip. The t-tests to determine if a significant increase above resting systolic blood pressure occurred during the sustained handgrip contractions indicated a significant response for each of the three different regression lines of handgrip, Table 15.

The individual and combined correlation coefficients of the exercising blood pressure measurements vs time for the sustained handgrip contractions are found in Appendix G, Table G-1. The combined correlation coefficient for these measurements was r = .95 ($p < .001$), indicating a

Table 15

Results of Student's t-Test Performed on Slopes and Intercepts of Regression Lines Representing Systolic Blood Pressure Responses to 40% MVC Handgrip Contractions (testing null hypothesis $H_o: \mu = 0$)

| | | Mean | Standard Error of the Mean | t* | p** | Degrees of Freedom |
|---|---|---|---|---|---|---|
| Session 2 | Slope | .309 | .035 | 8.71 | .0001 | 20 |
| | Intercept | 124.99 | 2.12 | 58.98 | .0001 | 20 |
| Session 3 | Slope | .265 | .028 | 9.35 | .0001 | 20 |
| | Intercept | 123.73 | 1.71 | 72.55 | .0001 | 20 |
| Mean | Slope | .287 | .026 | 6.48 | .0001 | 20 |
| | Intercept | 124.36 | 1.24 | 100.37 | .0001 | 20 |

*t for .05 level (20 D.F.) = 1.72

**probability of getting a larger t value

strong correlation between increasing blood pressure with time for the sustained handgrip contractions.

The between trial reproducibility of the slopes and intercepts of the regression lines representing the systolic blood pressure responses to the sustained handgrip contractions was demonstrated by calculating correlation coefficients of $r = .389$ for the slopes and $r = .675$ for the intercepts. Calculated t values of $t = 1.2$ for the slopes and $t = .78$ for the intercepts indicated no significant differences between paired values. As with the systolic blood pressure responses to the sustained adduction contractions, the systolic blood pressure responses of a subject to sustained handgrip contractions were not highly reproducible ($r = .389$) even though there was not a significant difference between a subject's two responses.

Adduction vs Handgrip. The results of the analyses of variance performed on the slopes and intercepts of the regression lines representing the mean response of the 21 subjects to the sustained contractions of the two different size muscle groups are shown in Tables 16 and 17. Significant differences between the slopes ($F = 68.11$, $p < .001$) and intercepts ($F = 4.95$, $p < .045$) of the mean regression lines were present.

Table 16

Summary of Analysis of Variance for Slopes of Regression Lines of Blood Pressure Responses to Sustained Index Finger Adduction and Hardgrip Contractions

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | F* | p** |
|---|---|---|---|---|---|
| Exercise | 1 | 1.158 | 1.158 | 138.40 | .0001 |
| Subjects | 20 | 0.338 | 0.017 | 2.04 | .0261 |
| Interaction | 20 | 0.341 | 0.017 | 2.04 | .0261 |
| Error | 42 | 0.351 | 0.008 | | |
| using the analysis of variance mean square for interaction as the error term since subjects were assumed to be a random sample | | | | | |
| Exercise | 1 | 1.158 | 1.158 | 68.11 | .0001 |
| Error | 20 | 0.341 | 0.017 | | |

*F for .05 level (1,20 D.F.) = 4.35
F for .05 level (20,40 D.F.) = 1.84
**probability of getting a larger F value

Table 17

Summary of Analysis of Variance for Intercepts of Regression Lines of Blood Pressure Responses to Sustained Index Finger Adduction and Handgrip Contractions

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | F* | p** |
|---|---|---|---|---|---|
| Exercise | 1 | 82.01 | 82.01 | 3.37 | .0735 |
| Subjects | 20 | 4663.11 | 233.16 | 9.58 | .0001 |
| Interaction | 20 | 357.41 | 17.87 | .73 | .7690 |
| Error | 42 | 1022.08 | 24.33 | | |
| using the analysis of variance mean square for interaction as the error term since subjects were assumed to be a random sample | | | | | |
| Exercise | 1 | 82.01 | 82.01 | 4.95 | .0447 |
| Error | 20 | 357.41 | 17.87 | | |

*F for .05 level (1,20 D.F.) = 4.35
F for .05 level (20,40 D.F.) = 1.84
**probability of getting a larger F value

The fact that a subject-exercise interaction was present for the slopes indicated that because a subject had a relatively strong response to the sustained index finger adduction contractions (as indicated by a relatively high slope) did not indicate that he would also have a relatively strong response to the sustained handgrip contractions. The significance of the subject-exercise interaction ($F = 2.04$) relative to the significance of the difference between the mean systolic blood pressure responses to the sustained contractions of the two different size muscle groups ($F = 68.11$) was negligible.

Since the paired t-test indicated no significance difference between resting systolic blood pressure values, one would assume that on the average a subject's resting systolic blood pressure was essentially the same when starting the different sustained contractions. The fact that the intercepts of the regression lines representing the mean systolic blood pressure responses to the two different size muscle groups were significantly different indicated that a significant increase in systolic blood pressure must have occurred early in the handgrip contractions. This would have simulated a seemingly higher starting point for the handgrip contractions.

## Summary

The analysis of variance and Duncan's multirange test indicated significant differences between the five index finger adduction MVC determinations performed by each subject. The same tests indicated no such differences were present for the corresponding handgrip values. The degree of within day reproducibility for the MVC determinations for index finger adduction was demonstrated by a correlation coefficient of r = .842 (max 1 vs max 2). The corresponding correlation for the handgrip MVC determinations was r = .843. The between day correlation coefficients for the index finger adduction MVC determinations ranged from r = .336 to r = .709 while the corresponding values for gandgrip ranged from r = .448 to r = .780.

The paired t-test indicated no significant difference existed between paired resting systolic blood pressures measured at the start of sessions 2 and 3.

The analysis of variance indicated no significant difference between each subject's endurance times for the sustained index finger adduction contractions. A significant difference was shown to exist between the corresponding endurance times for handgrip. Correlation

coefficients of r = .59 for index finger adduction and r = .65 for handgrip were calculated for the endurance times of the sustained contractions.

The t-tests indicated a significant increase above the resting systolic blood pressure occurred during each sustained contraction of the two different size muscle groups. The reproducibility of the slopes and intercepts of the regression lines representing the systolic blood pressure responses to the sustained index finger adduction contractions was indicated by correlation coefficients of r = .198 and r = .706, respectively. Correlation coefficients of r = .389 and r = .675 were calculated for the slopes and intercepts, respectively, of the regression lines representing the systolic blood pressure responses to handgrip.

The analyses of variance performed on the slopes and intercepts of the regression lines representing the mean responses of the 21 subjects to the sustained contractions of the two different size muscle groups demonstrated that a significant difference existed.

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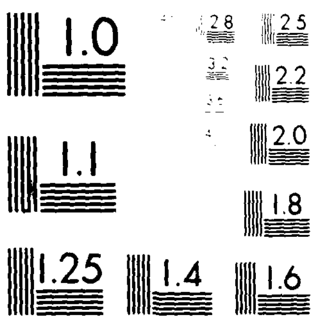



MICROCOPY RESOLUTION TEST CHART

# CHAPTER V

## DISCUSSION and CLINICAL IMPLICATIONS

### Strength Measurements

In a study such as this, one must be concerned with the reliability of repeated strength measurements. Studies have been conducted which looked specifically at this issue. Two items to be considered when evaluating the reliability of repeated maximum iscmetric strength measurements are between day and within day variaticns. Carlson and McCraw(17) obtained a between day test-retest correlation coefficient of .94. This was calculated from a total of 8 100% maximal voluntary strength determinations, each perfcrmed on a different day, for isometric elbow flexion by each of 36 subjects. In a study dealing with isometric handgrip strength, Heyward(18) obtained test-retest between day correlation coefficients ranging from .92 to .98 from a total of 11 100% maximal voluntary strength determinations perfcrmed by each of 49 subjects. Each 100% determination was performed on a different day with no more than three determinations in any one week. Even though the between

day correlation coefficients for both adduction and handgrip maximal voluntary strength values were relatively low ($r = .336$ to $.780$) the within day correlations were higher ($r = .842$ to $.843$).

The analysis of variance and Duncan's multirange test indicated a significant difference at the .05 level between the mean values of adduction MVC determinations for Group A (max 4, max 5, and max 3), Group B (max 5, max 3, and max 2), and Group C (max 3, max 2, and max 1)(Table 4). The same procedure, though, indicated no significant difference between corresponding handgrip strength values(Table 8). In trying to understand why the maximal adduction strength values were as variable and seemingly unreliable as they were one should consider the type of contraction involved and factors related to producing maximal strength in a muscle contraction. As mentioned earlier in this study, index finger adduction was chosen to represent the smaller muscle mass because of its relative ease of motor control. Even though it is fairly easy to isolate this movement, if stabilized properly, it still remains a relatively uncommon motion. This specific muscle action was chosen because it was the most natural, easily isolated small muscle action to produce. Due to the lower innervation ratio, as compared to a muscle mass

which produces a gross type of muscle action (i.e. biceps for elbow flexion), fine motor control is required to produce index finger adduction as an isolated contraction(37,38). With this in mind, one should consider Simonson and Lind's work in which they demonstrated "...the more complex the contraction, the more difficult it is to measure it accurately,"(15). Simonson and Lind(15) and Ikai and Steinhaus(39) all agree that motivation and mental concentration are extremely important in producing a maximal muscle contraction. Ikai and Steinhaus concluded that, especially when dealing with untrained subjects, supraspinal and proprioceptive inhibitions of varying degree will prevent the subject from engaging all the motor units of an active muscle at tetanus frequency. This fact, they concluded, gave credence to the idea that "...in every voluntarily executed, all out maximal effort, psychological rather than physiological factors determine the limits of performance,"(39).

Using the preceeding ideas of Ikai and Steinhaus, and disregarding the possibility of any additional muscle action aiding in producing the recorded tension, this investigator elected to choose the highest 100% MVC determination value (the highest of the five mean MVC

values calculated by averaging three brief contractions) for both index finger adduction and handgrip as being the value most likely to represent the true possible maximum strength for each of the muscle actions. This maximum strength value was then compared with the tension used during the fatigue contractions in sessions 2 and 3. Whereas this study was designed to look at the systolic blood pressure response to a 40% MVC of index finger adduction and handgrip, the preceding calculations revealed that the subjects in this study were more closely producing a 32% (±7%) index finger adduction and a 36% (±4%) handgrip contraction (Appendix H).

Resting Blood Pressure Measurements

Although the paired t-test indicated no significant difference at the .05 level between the resting blood pressures recorded at the start of session 2 and 3 and the low coefficients of variation (session 2 coefficient of variation = 8.05, session 3 coefficient of variation = 7.53) indicated a moderately homogeneous group of resting blood pressure values, one could possibly question their reliability on the basis of the correlation coefficient (r = .695). Sargent, et al. (40) conducted a study with 99 military recruits in the winter of 1954 and

the summer of 1955 which investigated the normal variability of resting systolic blood pressure. The subjects were divided into two groups and two resting blood pressures were taken at one week intervals on each subject, two pressures being taken in the winter and two taken in the summer. The results of the study revealed coefficients of variation ranging from 3.0 to 13.4. These relatively low coefficients of variation indicated that the variability of resting blood pressures among this rather large sample population was moderately small. Using three different techniques for measuring blood pressures, Sime, et al.( 41) took two resting blood pressure measurements on 31 subjects at one week intervals and compared the results of the three techniques. These techniques were: 1) auscultatory using a stethoscope and mercury manometer, 2) phonoarteriography, in which simultaneous recordings of pressure and Korotkoff sounds amplified through a stethoscope were photographed and measured, and 3) audio, which was identical to the phonoarteriographic method except the Korotkoff sounds were amplified electronically instead of with a stethoscope. This last method was identical, in theory to the primary method used in our study to measure systolic blood pressures. In comparing the paired resting blood

pressure values, Sime calculated r = .63, .76, and .62 respectively for the auscultatory, phonoarteriographic, and audio techniques. In the present study a correlation coefficient of r = .695, higher than Sime's r = .62 for his similar technique, was calculated for the resting systolic blood pressure values. With regard to the audio method, Sime states the "...high correlation coefficient demonstrates...reproducibility of systolic blood pressures."

One could conclude that based on the results of the paired t-test (page 62), the coefficients of variation and the correlation coefficient (Table 9, page 65), the resting systolic blood pressures measured in the present study are representative of a normal population and are within the limits of acceptable reproducibility.

<u>Endurance Times</u>

Although there were no significant differences between endurance times for the index finger adduction contractions, the analysis of variance indicated a significant difference between the endurance times for the handgrip contractions (Table 13, page 70). The longer duration of the second sustained handgrip contraction could have enabled a subject to attain a higher peak

systolic blood pressure. This could have changed the slope and intercept of the regression line characterizing the response to the exercise. There were, however, no systematic differences between the slopes and intercepts of the regression lines characterizing a subject's responses to the sustained handgrip contractions (page 74).

### Exercise Blood Pressure Responses

Since this investigator was unable to find any literature which characterized the blood pressure response to an exercise using a regression equation, there will be no comparisons or contrasts of the regression equations calculated in this study with previous finding of other authors. The correlation coefficient for the slopes and intercepts of the regression lines representing the mean responses of the 21 subjects to each of the two sustained contractions of each different size muscle group were low (adduction slope $r = .198$, intercept $r = .706$; handgrip slope $r = .389$, intercept $r = .675$). In spite of this low reproducibility for the regression lines, paired t-tests indicated no significant difference existed between the corresponding responses. One could deduce from this that a learning effect did not introduce a significant bias

into the blood pressure response of the second fatigue contraction.

Before comparing the regression lines representative of the mean systolic blood pressure responses of the 21 subjects to the two different size muscle groups, one must assume that, as the literature states, there will be a continuous rise in the blood pressure when a muscle is contracting at greater than 15% of it's maximal voluntary tension. One can see that there is approximately a six fold difference between the slopes of the two regression lines representing the systolic blood pressure responses (adduction = .052, handgrip = .287), Figure 13, page 70. If a 4% increase were added to the slope for the adduction response, as a compensation for the 4% less tension (32% versus 36%) used during the fatigue contractions, the difference between the two would remain essentially unchanged.

An attempt was made to find literature regarding the sensitivity of the cardiovascular response center(s) to different levels of isometric tension. Since different authors have reported the results of different studies in different ways (absolute arterial or aortic blood pressure measurements, mean (diastolic + 1/3 pulse pressure) arterial or mean aortic pressures, discreet time points,

and relative time of contraction), it was necessary to find studies by the same author in which the same techniques had been used to look at the blood pressure responses of muscle group(s) at different levels of isometric tension. In a previously mentioned study(34), Ramos reported a 12 mmHg increase in brachial artery pressure in response to a 10% increase (25%-35% MVC) in isometric tension. Ramos' data should be cautiously considered when compared with the data from the present study. Ramos instructed his subjects to maintain a predetermined relative handgrip tension for 5 minutes. After approximately 1.5 minutes at the 25% MVC and 1 minute at the 35% MVC levels there was a continuous increase of EMG activity in the more proximal flexor muscles of the ipsilateral extremity. This additional muscle activity, added to that of the primary handgrip muscles, significantly increased the size of the active muscle mass responsible for the observed systolic blood pressure responses. Thus, the blood pressure changes he observed were more abrupt than the responses observed in the present study.

Using the regression equation for the mean response to the adduction contraction ($y = .052x + 122.38$) and the mean time for the adduction contraction (136.72 seconds)

the peak systolic blood pressure attained in the present study was 129.5 mmHg. Adding a correction factor of 4.8 mmHg, based on Ramos' data, to compensate for the 4% difference between the adduction and handgrip relative tensions used in the study would increase this peak pressure to 134.3 mmHg. Substituting this value for y, the regression equation becomes y = .087x + 122.38. Even though this is a 67% increase in the adduction slope, there is still a three and one half fold difference between the slopes for the mean responses.

## Summary and Conclusion

Although the reproducibility and consequently the reliability of the within day maximal strength determinations were readily acceptable, the between day maximal strength determinations were not as reproducible. Possible explanations as to why these between day strength values varied as they did were: 1)the relative ease of performance of the two different contractions, 2) the motor control needed to produce the more refined movement of index finger adduction as compared to the gross handgrip contraction and, 3) the motivation and mental concentration of the individual subjects from day to day.

The resting systolic blood pressure values measured in this study were representative of a normal sampling of individuals.

The technique used to characterize the systolic blood pressure responses (linear regression of the blood pressure vs time data points) introduced a unique method for presenting blood pressure data. Future investigations using this same technique will allow for a valid comparison of results even though the actual experimental conditions may vary.

The fact that the index finger adduction and handgrip fatigue contractions were performed at 32% and 36% MVC, respectively, was acknowledged. Using the most critical and exacting compensation, the systolic blood pressure response to handgrip remained demonstrably different than that to the index finger contraction.

## Recommendations for Future Studies

As a continuation of the present study, other studies could be conducted which would: 1) characterize the systolic blood pressure response of other isolated movements involving larger muscle masses, 2) characterize the additive effects of simultaneous muscle contractions

of a known mass to a previously described systolic blood pressure response 3) compare the systolic blood pressure response of individuals with various circulatory problems (i.e. hypertension, post cardiac infarction) to those of normal individuals, and 4) define the critical size muscle mass, if one exists, below which the systolic blood pressure response to an isometric contraction is dependent on the size of the contracting muscle mass and above which the systolic blood pressure response is dependent on the percentage of MVC at which the muscle mass is contracting.

## Clinical Implications

The results of the present study could be utilized in advising patients with severe hypertension and post cardiac infarction patients concerning ADL activities and possible employment opportunities. Theoretical peak systolic blood pressures could be calculated for an activity, illustrating the potential hazard to the patient. By combining these results with those of the proposed future studies, though, the scope of the clinical implications would be greatly expanded. This data could then be used as a preliminary screening procedure for isometric exercise induced hypertension and as a means of

testing the efficacy of drugs used for treating hypertension. Clinicians, using biofeedback techniques, could teach individuals how to relax certain muscles. This could be used as a treatment for certain types of hypertension and migraine headaches. Future studies could provide data which would be of benefit in exercise prescription and employment counseling for patients with cardio-vascular problems.

# CHAPTER VI

## SUMMARY of THESIS

### Purpose of the Study

The purpose of this study was to investigate the difference between the blood pressure responses to two different size muscle masses contracting at a known percentage of maximal voluntary strength. Specifically, this study compared slopes and intercepts of the regression lines derived from systolic blood pressure responses to two different size muscle groups contracting at 40% maximal voluntary strength.

### Procedure

Based on a 100% MVC value derived from two MVC determinations performed by each of 21 male subjects, a 40% MVC value was determined for index finger adduction and handgrip. During each of the two succeeding sessions, each subject performed a sustained 40% isometric contraction of the two exercises while systolic blood pressure and surface EMG activity over selected muscle groups was being monitered. Following each sustained

contraction, a maximal EMG response from the monitered muscle groups and a 100% MVC of the appropriate isometric contraction was produced. The final session with each subject was a 100% MVC determination of each of the two different contractions.

Results

Although the analysis of variance and Duncan's multirange test demonstrated a trend of increasing tension in the 100% index finger adduction values from max 1 to max 5, there was no similar occurrence in the corresponding handgrip values. The correlation coefficient (r), used as an index of reproducibility, indicated that the 100% index finger adduction values were not as reproducible as the corresponding handgrip measurements.

There was no statistically significant difference between the resting systolic blood pressures measured on each subject at the start of sessions 2 and 3.

The difference between corresponding slopes and intercepts of the two regression lines representing each subject's responses to repeated sustained contractions of the two different size muscle groups was statistically insignificant.

Even though the analysis of variance indicated a statistically significant subject-exercise interaction, the same procedure indicated that an even larger statistically significant difference existed between the different blood pressure responses to the two different isometric contractions (index finger adduction vs handgrip).

Conclusion

There is a statistically significant difference in the systolic blood pressure response to a sustained 40% MVC for index finger adduction and a sustained 40% handgrip contraction.

# APPENDIX A

## MEDICAL HISTORY, SUBJECT INFORMATION, AND CERTIFICATION OF SUBJECT CONSENT FORMS

# MEDICAL HISTORY FORM

NAME: ______________________________ DATE: _______________

Have you ever had any known indications of, or been treated for, any of the following (underline applicable item)

| | | YES | NO |
|---|---|---|---|
| 1. | High blood pressure? (If "yes", list drugs prescribed and dates taken.) | ___ | ___ |
| 2. | Chest pain, heart attack, rheumatic fever, heart murmur, irregular pulse or other disorder of the heart or blood vessels? | ___ | ___ |
| 3. | Cancer, tumor, cyst, or any disorder of the thyroid, skin, or lymph glands? | ___ | ___ |
| 4. | Diabetes or anemia or other blood disorder? | ___ | ___ |
| 5. | Sugar, albumin, blood or pus in the urine, or veneral disease? | ___ | ___ |
| 6. | Any disorder of the kidney, bladder, postate, breast or reproductive organs? | ___ | ___ |
| 7. | Ulcer, intestinal bleeding, hepatitis, colitis, or other disorder of the stomach, intestine, spleen, pancreas, liver or gall bladder? | ___ | ___ |
| 8. | Asthma, tuberculosis, bronchitis, emphysema or other disorder of the lungs? | ___ | ___ |
| 9. | Fainting, convulsions, migraine headache, paralysis, epilepsy or any mental or nervous disorder? | ___ | ___ |
| 10. | Arthritis, gout, amputation, sciatica, back pain or other disorder of the muscles, bones, or joints? | ___ | ___ |

MEDICAL HISTORY FORM (cont'd.)

11. Disorder of the eyes, ears, nose, throat or sinuses? ___ ___

12. Varicose veins, hemorrhoids, hernia or rectal disorders? ___ ___

13. Alcholism or drug habit? ___ ___

Have you:

14. Had, or been advised to have, an x-ray, cardiogram, blood or other diagnostic test in the past 5 years? ___ ___

15. Been a patient in a hospital, clinic, or other medical facility in the past 5 years? ___ ___

16. Ever had a surgical operation performed or advised? ___ ___

17. Had any oral or respiratory infections in the past week? ___ ___

---

DETAILS OF "YES" ANSWERS.
Include number of attacks, dates:

SUBJECT INFORMATION SHEET

Project Title: CHANGES IN SYSTOLIC BLOOD PRESSURE DURING ISOMETRIC CONTRACTIONS OF DIFFERENT SIZE MUSCLE GROUPS

Investigators: Joe A. Buck, L.P.T.
Louis R. Amundsen, L.P.T., Ph.D.

This experiment involves the determination of your maximal isometric strength for adducting (pulling toward the hand) your index finger and gripping with the entire hand. Following these determinations you will be trained to perform the above contractions at 40% of your maximum isometric strength with minimal activity in other muscles. After this initial training your blood pressure responses to 40% of maximal capacity contractions held to tolerance widd be assessed for each muscle group.

Four sessions will be needed for training and data collection.

Our monitoring equipment should cause no discomfort. We will use only noninvasive methods to monitor your heart rate, blood pressure, and electromyographic responses to exercise. The exercise may cause some local muscular discomfort during prolonged contractions.

We expect the results of this experiment to enhance the knowledge base required to determine if given occupational or recreational activities are safe for patients with ischemic heart disease.

"I have discussed the above points with the subject or his legally authorized representative, using a translator if necessary. It is my opinion that the subject understands the risks, benefits and obligations involved in participation in this project."

---------------------------------
Investigator

# CERTIFICATION OF SUBJECT CONSENT

Project Title: CHANGES IN SYSTOLIC BLOOD PRESSURE DURING ISOMETRIC CONTRACTIONS OF DIFFERENT SIZE MUSCLE GROUPS

Investigators: Louis R. Amundsen, L.P.T., PhD.
Joe A. Buck, L.P.T.

I, ________________________________, hereby certify that I have been told by L.R. Amundsen or _______________ of the physical therapy department about the research on isometric exercise and its purposes. I understand the possible discomforts and risks and the possible benefits relating to this research project.

A written summary of what I have been told is attached. I have been given an adequate opportunity to read it.

I understand that I have the right to ask questions about any procedure and to withdraw my consent and stop taking part in the project at any time without prejudice to me.

I herby freely consent to take part in this research project.

________________________________
(signature of subject)

I, the undersigned, certify that I was present during the oral presentation of the written summary attached when it was given to the above subject.

________________________________
(signature of auditor-witness)

# APPENDIX B

## CALIBRATION OF FORCE MEASURING TRANSDUCERS

The calibration for each "O" ring force transducer was conducted as follows. The maximum weight to be used was suspended from the appropriate transducer and an appropriate sensitivity setting for the pre-amp and amplifier of the respective channel for each transducer was determined. The weight was then systematically reduced through the range in which the "O" ring was to be used. A graph representing the calibration data for the small "O" ring used to measure the index finger adduction and the regression equation generated from this set of data is found in Figure B-1. The maximum deviation from this line was negligible (.035 lbs), producing a linearity (max deviation/ full scale deflection) of $< \pm.1\%$ of full scale. Similarly, the data for the calibration of the transducer used to measure the handgrip force is given in Table B-1. Its corresponding graph and regression equation are illustrated in Figure B-2. The linearity of this transducer was within $\pm.7\%$ of full scale.

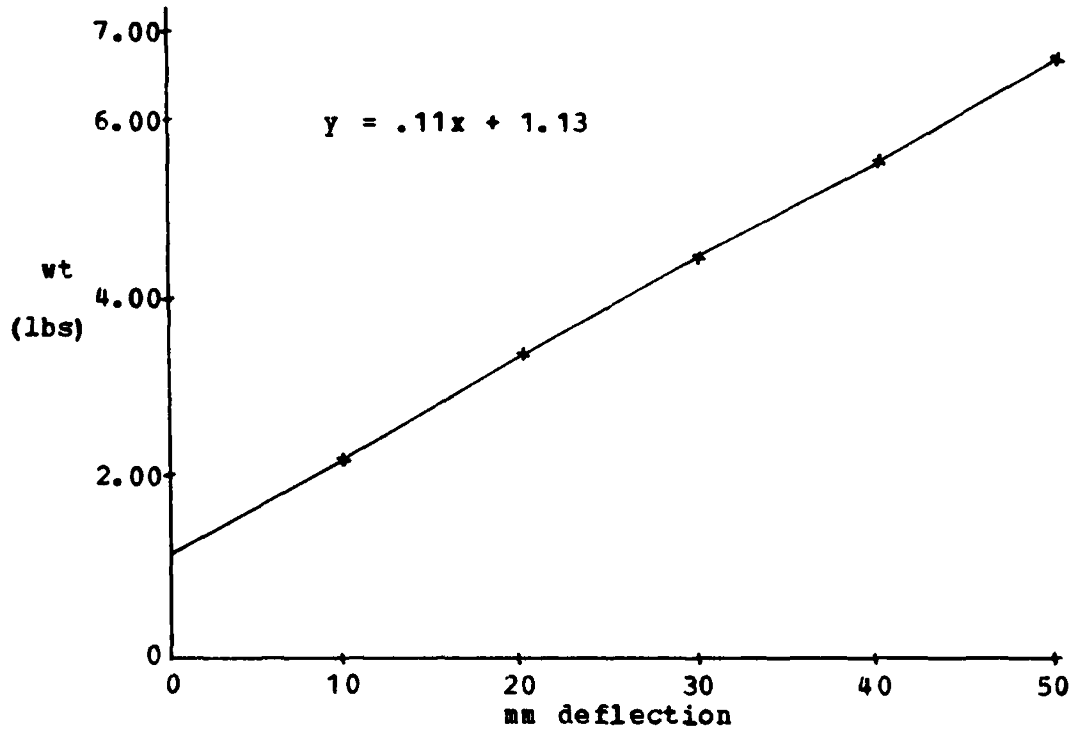



Figure B-1

Calibration Data and Regression Equation for Force Transducer Used to Measure Index Finger Adduction Strength

Table B-1

Calibration Data for Force Transducer
Used to Measure Handgrip Strength

| Wt. (lbs) | mm Deflection |
|---|---|
| 165.50 | 46.33 |
| 155.00 | 43.00 |
| 145.00 | 40.00 |
| 135.25 | 36.33 |
| 124.75 | 33.00 |
| 114.75 | 30.00 |
| 105.75 | 26.33 |
| 95.50 | 23.33 |
| 85.00 | 19.33 |
| 75.00 | 16.00 |
| 65.00 | 13.00 |
| 54.50 | 9.33 |
| 45.50 | 6.00 |
| 35.50 | 3.00 |
| 25.00 | 0.00 |

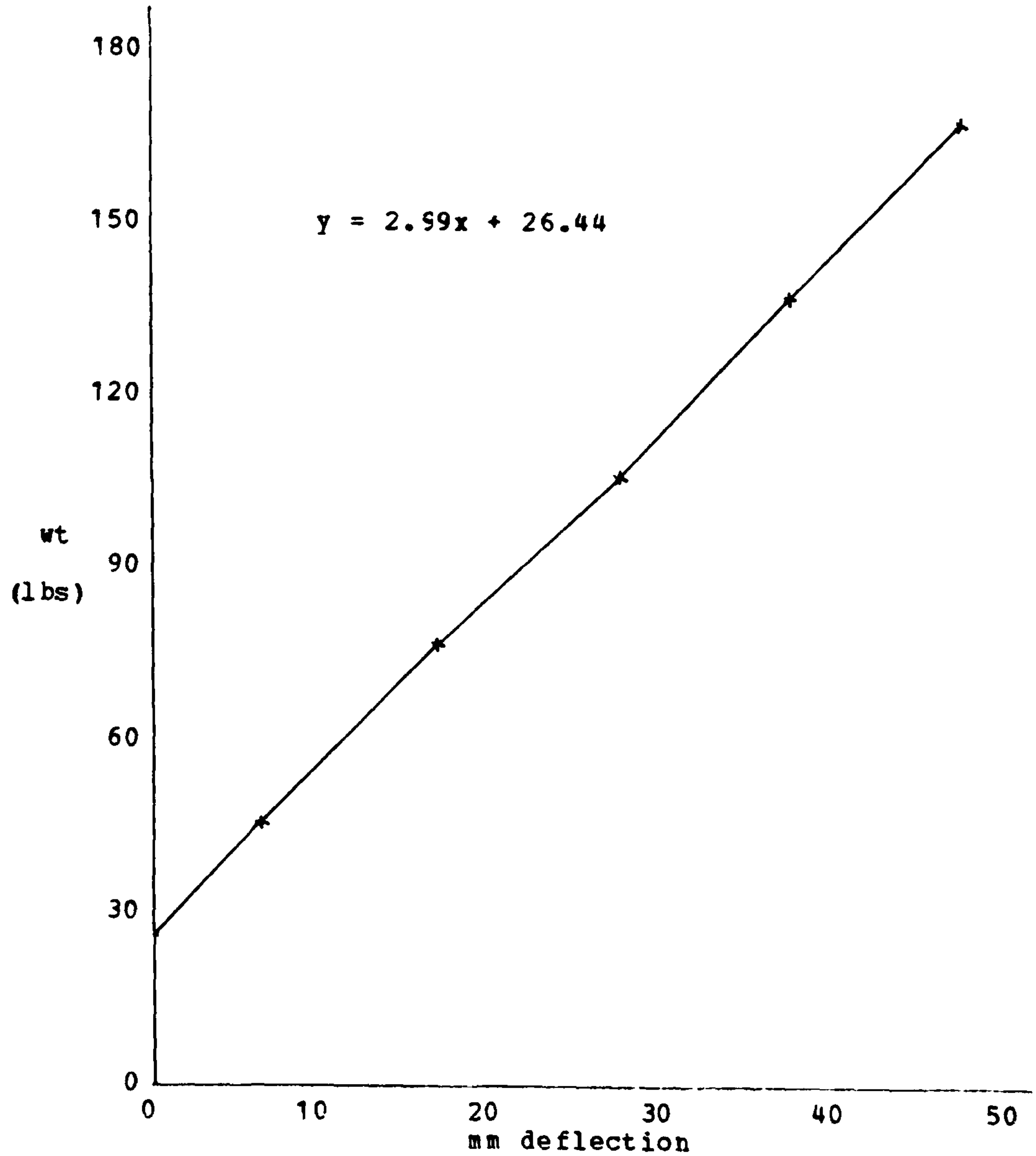



Figure B-2

Calibration Data and Regression Equation for Force Transducer Used to Measure Handgrip Strength

# APPENDIX C

## COMPARISON OF KOROTKOFF SIGNALS AMPLIFIED THROUGH THE BECKMAN MODEL 9863A INDIRECT BLOOD PRESSURE COUPLER AND SYSTOLIC BLOOD PRESSURE MEASURED VIA THE AUSCULTATORY METHOD USING A STETHOSCOPE AND MERCURY MANOMETER

Table C-1

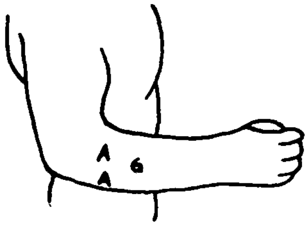
Comparison of Korotkoff Signals Amplified Through the Beckman Model 9863A Indirect Blood Pressure Coupler and Systolic Blood Pressure Measured Via the Auscultatory Method Using a Stethoscope and Mercury Manometer

| S.B.P. Measured from Korotkoff Signals | S.B.P. Measured With Stethescope and Mercury Manometer |
|---|---|
| 125 | 129 |
| 124 | 124 |
| 115 | 115 |
| 115 | 114 |
| 120 | 118 |
| 117.5 | 116 |

# APPENDIX D

## LOCATION OF SURFACE EMG ELECTRODES

WRIST EXTENSORS



Draw a line from the lateral epicondyle of the humerus to the styloid process of the ulna. 25% of this distance draw a perpendicular line laterally (1 inch) that will put an active electrode on the extensor carpi ulnaris. Draw a 2 inch equilateral triangle from this point.

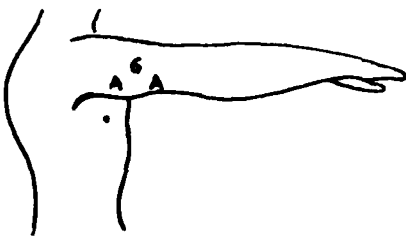
WRIST FLEXORS

Draw a line from the medial epicondyle of the humerus to the styloid process of the radius. 20% of this distance from the medial epicondyle on the line is the ground electrode, 50% of the distance on the line is an active electrode. Draw a 2 inch equilateral triangle medially from these points.

BICEPS

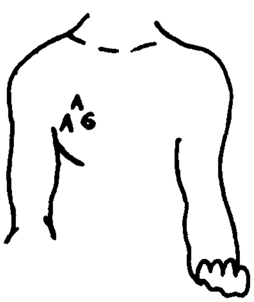
Draw a line from the coracoid process to the biceps tendon in the elbow flexion crease. 25% of the distance from the crease on the line is the ground electrode. Draw a 2 inch equilateral triangle proximally with the ground electrode as the apex.

TRICEPS



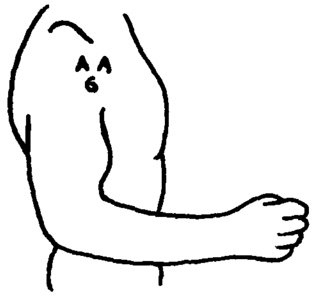
Draw a line from the olecranon to the middle of the acromion. 60% of the distance from the acromion on the line is the groumd electrode. Draw a 2 inch equilateral triangle medially.

PECTORALIS MAJOR



From the mid-point on the distal sternal-acromial line draw a perpendicular cross line. 1 inch each way from the sternal-acromial line are the active electrodes. 1 inch toward the sternum from the mid-point is the ground electrode.

DELTOIDS




Draw a line from the lateral epicondyle of the humerus to the acromion. 13% of the distance from the proximal point draw a perpendicular line anterior across the anterior deltoid. 6% of the distance from the acromio-lateral epicondyle line on the anterior line is an active electrode, the other active electrode is on the same line 2 inches away. Draw a 2 inch equilateral triangle distally for the ground electrode.

# APPENDIX E

## PORTION OF CHART RECORD PRODUCED DURING A SUSTAINED 40% MVC INDEX FINGER ADDUCTION CONTRACTION

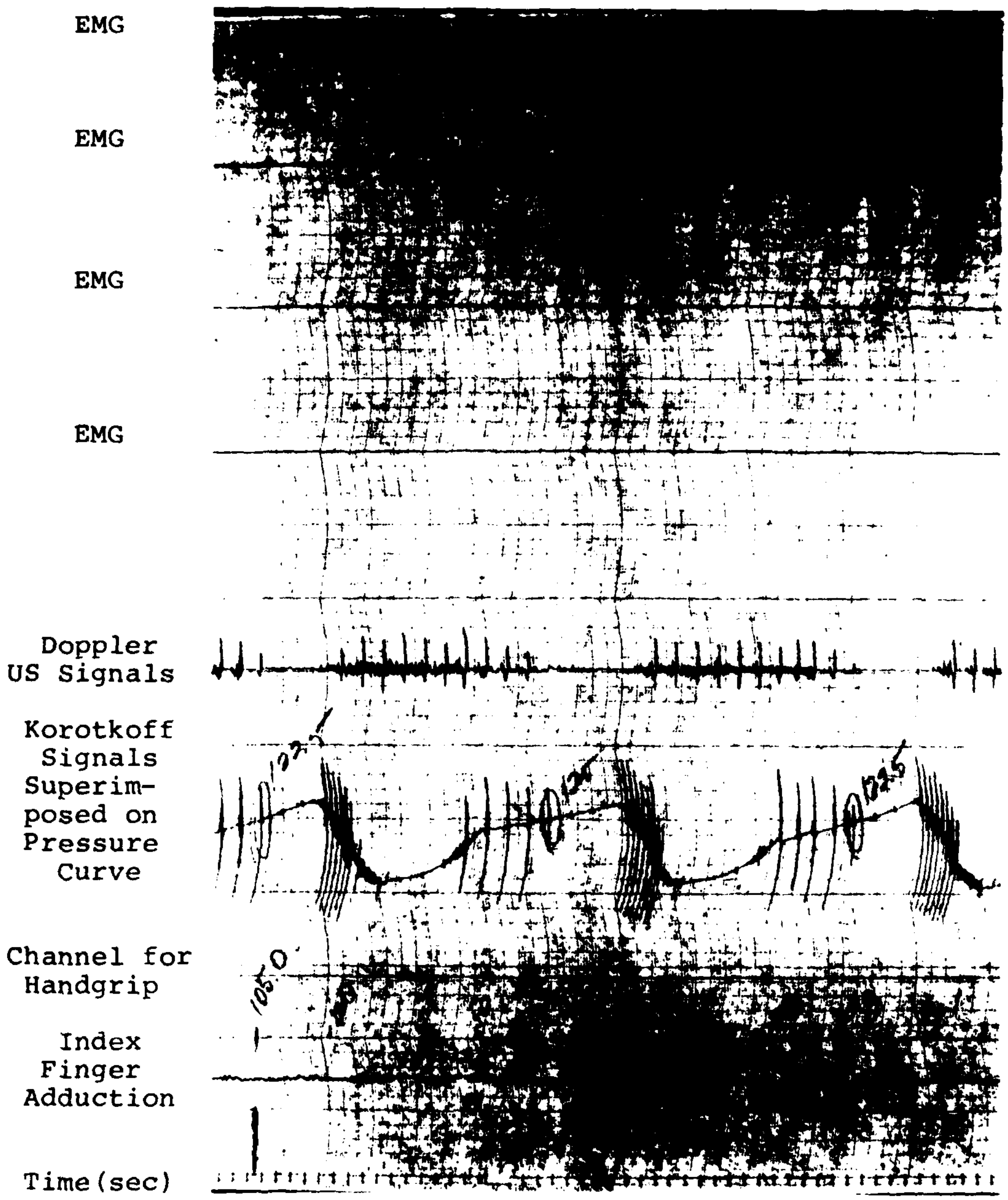



Figure E-1

Portion of Chart Record Produced During a Sustained 40% MVC Index Finger Adduction Contraction

# APPENDIX F

## CORRELATION COEFFICIENTS AND STATISTICAL SIGNIFICANCE OF CORRELATION COEFFICIENTS OF TIME VS SYSTOLIC BLOOD PRESSURE FOR SUSTAINED 40% MVC INDEX FINGER ADDUCTION CONTRACTIONS

Table F-1

Correlation Coefficients for Time vs Systolic Blood Pressure for 40% MVC Index Finger Adduction

| Subject | Repetition | $N_i$ | $w_i$* | $r_i$ | $z_i$** | $z_w$+ | $(w_i z_i^2)$ |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 5 | 2 | .72 | .91 | 1.82 | 1.66 |
| | 2 | 9 | 6 | .46 | .50 | 3.00 | 1.50 |
| 2 | 1 | 5 | 2 | .82 | 1.16 | 2.32 | 2.69 |
| | 2 | 6 | 3 | .71 | .89 | 2.67 | 2.38 |
| 3 | 1 | 7 | 4 | .80 | 1.10 | 4.40 | 4.84 |
| | 2 | 11 | 8 | .04 | .04 | .32 | .01 |
| 4 | 1 | 7 | 4 | .60 | .69 | 2.67 | 1.90 |
| | 2 | 6 | 3 | .04 | .04 | .12 | .00 |
| 5 | 1 | 5 | 2 | .17 | .17 | .34 | .06 |
| | 2 | 6 | 3 | .85 | 1.26 | 3.78 | 4.76 |
| 6 | 1 | 7 | 4 | .69 | .85 | 3.40 | 2.89 |
| | 2 | 7 | 4 | .53 | .59 | 2.36 | 1.39 |
| 7 | 1 | 7 | 4 | .33 | .34 | 1.36 | .46 |
| | 2 | 8 | 5 | .17 | .17 | .85 | .14 |
| 8 | 1 | 6 | 3 | .32 | .33 | .99 | .33 |
| | 2 | 5 | 2 | .47 | .51 | 1.02 | .52 |
| 9 | 1 | 5 | 2 | .51 | .56 | 1.12 | .63 |
| | 2 | 4 | 1 | .76 | 1.00 | 1.00 | 1.00 |
| 10 | 1 | 6 | 3 | .88 | 1.38 | 4.14 | 5.71 |
| | 2 | 4 | 1 | .36 | .38 | .38 | .14 |
| 11 | 1 | 10 | 7 | .88 | 1.38 | 9.66 | 13.33 |
| | 2 | 9 | 6 | .30 | .31 | 1.86 | .58 |
| 12 | 1 | 6 | 3 | .55 | .62 | 1.86 | 1.15 |
| | 2 | 8 | 5 | .83 | 1.19 | 5.95 | 7.08 |
| 13 | 1 | 8 | 5 | .44 | .47 | 2.35 | 1.10 |
| | 2 | 8 | 5 | .80 | 1.10 | 5.50 | 6.05 |
| 14 | 1 | 5 | 2 | .73 | .93 | 1.86 | 1.73 |
| | 2 | 4 | 1 | 1.00 | 2.90 | 2.90 | 8.41 |
| 15 | 1 | 7 | 4 | .65 | .78 | 3.12 | 2.43 |
| | 2 | 7 | 4 | .29 | .30 | 1.20 | .36 |
| 16 | 1 | 8 | 5 | .67 | .81 | 4.05 | 3.28 |
| | 2 | 9 | 6 | .66 | .79 | 4.74 | 3.74 |
| 17 | 1 | 6 | 3 | .58 | .66 | 1.98 | 1.31 |
| | 2 | 8 | 5 | .01 | .01 | .05 | .00 |
| 18 | 1 | 8 | 5 | .01 | .01 | .05 | .00 |
| | 2 | 9 | 6 | .89 | 1.42 | 8.52 | 12.10 |

Table F-1 (cont'd.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 19 | 1 | 7 | 4 | .58 | .66 | 2.64 | 1.74 |
| | 2 | 6 | 3 | .48 | .52 | 1.56 | .81 |
| 20 | 1 | 8 | 5 | .72 | .91 | 4.55 | 4.14 |
| | 2 | 8 | 5 | .50 | .55 | 2.75 | 1.51 |
| 21 | 1 | 10 | 7 | .60 | .69 | 4.83 | 3.33 |
| | 2 | 9 | 6 | .54 | .60 | 3.60 | 2.16 |
| Total | | | 168 | | | 113.73 | 109.39 |

$$z = \Sigma w_i z_i / \Sigma w_i = .68$$

$$\bar{r} = e^{2z} - 1 / e^{2z} + 1 = .59^{++}$$

$$*w_i = N_i - 3$$
$$**z_i = 1/2[\log_e(1+r) - \log_e(1-r)]$$
$$^{+}z_w = w_i z_i$$

++To test the hypothesis that several r's are from the same rho, and to combine them into an estimate of rho:

$$X^2 = (\Sigma w_i z_i{}^2) - [(\Sigma w_i z_i)^2 / (\Sigma w_i)]$$
$$X^2 = 32.40$$
$$X^2 (.05 \text{ level, } 41 \text{ D. F.}) = 56.9$$

probability = .17 of observing a $X^2 \geq 32.40$ when the underlying correlations are from a common population

To test the hypothesis that rho has some value other than 0 (rho≠0): use the fact that when rho = 0, z has a normal distribution with mean = 0 and variance = $1/\sqrt{\Sigma(w_i)}$. Reject the hypothesis that rho = 0

at the .05 level if $\sqrt{\Sigma(w_i)}\ (z_w) > 1.96$

at the .01 level if $\sqrt{\Sigma(w_i)}\ (z_w) > 2.57$

at the .001 level if $\sqrt{\Sigma(w_i)}\ (z_w) > 3.27$

Since $\sqrt{168}$ (.68) = 8.81 we can reject the null hypothesis (that a correlation this high could occur by random sampling) at the .001 level.

# APPENDIX G

## CORRELATION COEFFICIENTS AND STATISTICAL SIGNIFICANCE OF CORRELATION COEFFICIENTS OF TIME VS SYSTOLIC BLOOD PRESSURE FOR SUSTAINED 40% MVC HANDGRIP CONTRACTIONS

Table G-1

Correlation Coefficients for Time vs Systolic Blood Pressure for 40% MVC Handgrip

| Subject | Repetition | $N_i$ | $w_i$* | $r_i$ | $z_i$** | $z_w$+ | $(w_i z_i^2)$ |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 3 | 0 | .94 | 1.74 | 0 | 0 |
| | 2 | 4 | 1 | .98 | 2.30 | 2.30 | 5.29 |
| 2 | 1 | 3 | 0 | .92 | 1.59 | 0 | 0 |
| | 2 | 5 | 2 | .68 | .83 | 1.62 | 1.38 |
| 3 | 1 | 5 | 2 | .90 | 1.47 | 2.94 | 4.32 |
| | 2 | 6 | 3 | .84 | 1.22 | 3.66 | 4.47 |
| 4 | 1 | 7 | 4 | .93 | 1.66 | 6.64 | 11.02 |
| | 2 | 11 | 8 | .95 | 1.83 | 14.64 | 26.45 |
| 5 | 1 | 5 | 2 | .97 | 2.09 | 4.18 | 8.47 |
| | 2 | 8 | 5 | .98 | 2.30 | 11.50 | 26.45 |
| 6 | 1 | 5 | 2 | .97 | 2.09 | 4.18 | 8.74 |
| | 2 | 6 | 3 | .97 | 2.09 | 4.18 | 13.10 |
| 7 | 1 | 5 | 2 | .93 | 1.66 | 3.32 | 5.51 |
| | 2 | 6 | 3 | .98 | 2.30 | 6.90 | 15.87 |
| 8 | 1 | 8 | 5 | .96 | 1.95 | 9.75 | 19.01 |
| | 2 | 9 | 6 | .94 | 1.74 | 10.44 | 18.17 |
| 9 | 1 | 6 | 3 | .82 | 1.16 | 3.48 | 4.04 |
| | 2 | 6 | 3 | .98 | 2.30 | 6.90 | 15.87 |
| 10 | 1 | 7 | 4 | .97 | 2.09 | 8.36 | 17.47 |
| | 2 | 8 | 5 | .99 | 2.65 | 13.25 | 35.11 |
| 11 | 1 | 9 | 6 | .74 | .95 | 5.70 | 5.42 |
| | 2 | 7 | 4 | .97 | 2.09 | 8.36 | 17.47 |
| 12 | 1 | 6 | 3 | .86 | 1.29 | 3.87 | 4.99 |
| | 2 | 7 | 4 | .96 | 1.95 | 7.80 | 15.21 |
| 13 | 1 | 7 | 4 | .99 | 2.65 | 10.60 | 28.09 |
| | 2 | 9 | 6 | .93 | 1.66 | 9.96 | 16.53 |
| 14 | 1 | 5 | 2 | .98 | 2.30 | 4.60 | 10.58 |
| | 2 | 5 | 2 | 1.00 | 2.90 | 5.80 | 16.82 |
| 15 | 1 | 8 | 5 | .87 | 1.33 | 6.65 | 8.84 |
| | 2 | 11 | 8 | .84 | 1.22 | 9.76 | 11.91 |
| 16 | 1 | 8 | 5 | .85 | 1.26 | 6.30 | 7.94 |
| | 2 | 7 | 4 | .95 | 1.83 | 7.32 | 13.40 |
| 17 | 1 | 7 | 4 | .28 | .29 | 1.16 | .34 |
| | 2 | 5 | 2 | .92 | 1.59 | 3.18 | 5.06 |
| 18 | 1 | 7 | 4 | .98 | 2.30 | 9.20 | 21.16 |
| | 2 | 7 | 4 | .65 | .78 | 3.12 | 2.43 |

Table G-1 (cont'd.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 19 | 1 | 4 | 1 | .96 | 1.95 | 1.95 | 3.80 |
| | 2 | 8 | 5 | .61 | .71 | 3.51 | 2.52 |
| 20 | 1 | 5 | 2 | .91 | 1.53 | 3.06 | 4.68 |
| | 2 | 8 | 5 | .95 | 1.83 | 9.15 | 16.74 |
| 21 | 1 | 6 | 3 | .91 | 1.53 | 4.59 | 7.02 |
| | 2 | 7 | 4 | .94 | 1.74 | 6.96 | 12.11 |
| Total | | | 150 | | | 250.84 | 474.41 |

$$z = \Sigma w_i z_i / \Sigma w_i = 1.67$$

$$\bar{r} = e^{2z} - 1/e^{2z} + 1 = .95^{++}$$

$$*w_i = N_i - 3$$
$$**z_i = 1/2[\log_e(1+r) - \log_e(1-r)]$$
$$+z_w = w_i z_i$$

++To test the hypothesis that several r's are from the same rho, and to combine them into an estimate of rho:

$$X^2 = (\Sigma w_i z_i^2) - [(\Sigma w_i z_i)^2 / (\Sigma w_i)]$$
$$X^2 = 54.94$$
$$X^2 (.05 \text{ level, } 41 \text{ D.F.}) = 56.9$$

probability = .07 of observing a $X^2 \geq 54.94$ when the underlying correlations are from a common population

To test the hypothesis that rho has some value other than 0 (rho ≠ 0) use the fact that when rho = 0, z has a normal distribution with mean = 0 and variance = $1/\sqrt{\Sigma(w_i)}$.

Reject the hypothesis that rho = 0

at the .05 level if $\sqrt{\Sigma(w_i)}\ (z_w) > 1.96$

at the .01 level if $\sqrt{\Sigma(w_i)}\ (z_w) > 2.57$

at the .001 level if $\sqrt{\Sigma(w_i)}\ (z_w) > 3.27$

Since $\sqrt{150}$ (1.67) = 20.45 we can reject the null hypothesis (that a correlation this high could occur by random sampling) at the .001 level.

# APPENDIX H

## ACTUAL PERCENTAGE OF MVC USED DURING SUSTAINED 40% ISOMETRIC CONTRACTIONS

Table H-1

Actual Percentage of MVC Used During Sustained Index Finger Adduction Contractions

| Subject | 40% value used/ Highest Recorded Max | Actual Percentage |
|---|---|---|
| 1 | .96/4.73 | .20 |
| 2 | 1.64/4.11 | .40 |
| 3 | .92/4.58 | .20 |
| 4 | .78/4.37 | .18 |
| 5 | 1.45/4.18 | .35 |
| 6 | 1.34/3.65 | .37 |
| 7 | 1.02/2.97 | .34 |
| 8 | 1.59/5.35 | .30 |
| 9 | 2.16/5.42 | .40 |
| 10 | 1.71/4.57 | .37 |
| 11 | 1.37/3.92 | .35 |
| 12 | 1.52/4.79 | .32 |
| 13 | 1.41/3.52 | .40 |
| 14 | 1.54/5.46 | .28 |
| 15 | 1.62/4.76 | .34 |
| 16 | 1.62/5.97 | .38 |
| 17 | 1.36/4.21 | .32 |
| 18 | 1.50/5.08 | .29 |
| 19 | .91/2.67 | .40 |
| 20 | 1.32/5.19 | .26 |
| 21 | 1.61/4.53 | .36 |
| | | Mean = .32 |
| | | S.D. = .07 |

Table H-2

Actual Percentage of MVC Used During Sustained Handgrip Contractions

| Subject | 40% Value Used/ Highest Recorded Max | Actual Percentage |
|---|---|---|
| 1 | 41.8/129.4 | .32 |
| 2 | 56.3/140.6 | .40 |
| 3 | 62.0/157.0 | .40 |
| 4 | 47.0/117.7 | .40 |
| 5 | 53.8/135.0 | .40 |
| 6 | 62.1/155.2 | .40 |
| 7 | 43.3/119.3 | .36 |
| 8 | 41.9/116.9 | .36 |
| 9 | 50.4/133.7 | .38 |
| 10 | 40.8/106.7 | .38 |
| 11 | 37.4/101.4 | .37 |
| 12 | 52.2/130.5 | .40 |
| 13 | 53.6/135.9 | .39 |
| 14 | 48.1/120.2 | .40 |
| 15 | 44.2/160.3 | .28 |
| 16 | 49.4/136.1 | .36 |
| 17 | 39.9/ 99.7 | .40 |
| 18 | 55.2/146.8 | .38 |
| 19 | 45.3/130.5 | .35 |
| 20 | 40.2/139.3 | .29 |
| 21 | 40.2/133.3 | .30 |
| | | Mean = .36 |
| | | S.D. = .04 |

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